U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

2020 SETO PEER REVIEW

STRATEGY AND PLANNING CHAIRS AND REVIEWERS

April 6, 2020

Elaine Ulrich, PhD, Senior Advisor

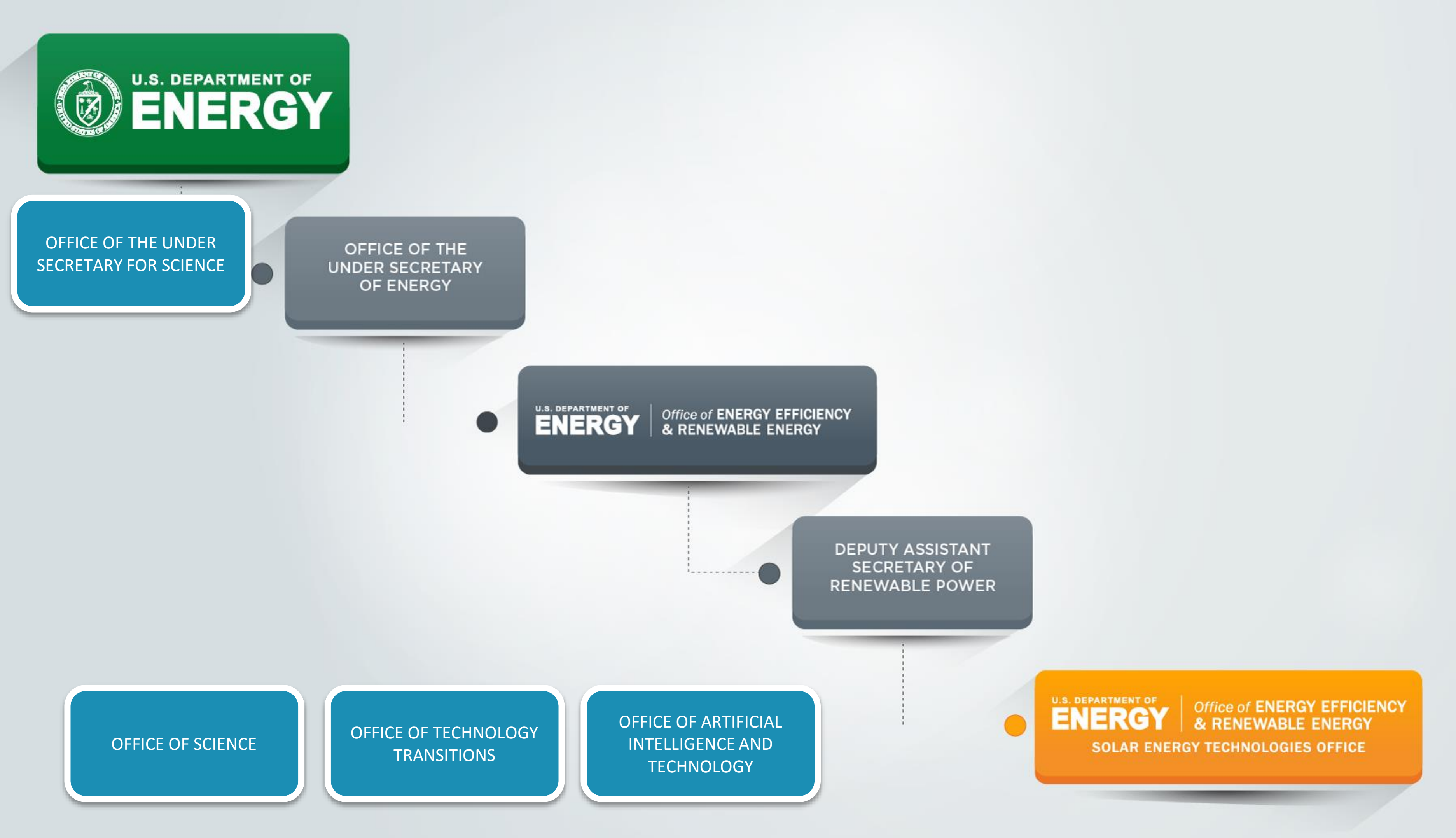
Garrett Nilsen, Andrew Dawson

energy.gov/solar-office

Strategy and Planning Overview

- Role, mission, and strategic tools
- Budget and Congressional Direction
- Strategic Analysis and Tools
- Collaborations and Special Projects

Where Does SETO Fit Within the Energy Department?



Government Role in Supporting Energy Transformation

Connect These with User Centered Design Approaches

Supply side: Innovation

- Support specific innovations (technology or market solutions)
- Enhance the Innovation Ecosystem

- Identifying emerging solutions
- Driving new intersections and connections across fields
- Widening the funnel of solutions being tested
- Testing, validation, data sharing to decrease risk
- Increase diversity of participants
- Provide opportunities for showcases and recognition
- Support new partnerships

Demand side: Empowerment and Participation

Access
Choice
Equity

Need to balance across these

- Transparency and Public information
- Consumer Protection
- Inclusion of Multi-Technology Options
- Cost, Benefit and Value considerations
- Social (DE&I, health, jobs), Environmental
- Public Participation Processes

Support change and leadership across supply and demand

Solar Energy Technologies Office Mission

Our mission is to accelerate the development and application of technology to advance low-cost, reliable solar energy in the U.S.

To achieve this mission, solar energy must:

- Be **affordable** and **accessible** for all Americans
- Support the **reliability**, **resilience**, and **security** of the grid
- Create a sustainable industry that **supports jobs**, **manufacturing**, and the **circular economy** in a wide range of applications

Solar Energy Technologies Office

WHAT WE DO

The Solar Energy Technologies Office (SETO) funds early-stage research and development in three technology areas: photovoltaics (PV), concentrating solar-thermal power (CSP), and systems integration with the goal of improving the **affordability**, **performance**, and **value** of solar technologies on the grid.

HOW WE DO IT

Advance solar technology to drive U.S. leadership in innovation and reductions in solar electricity costs.

Enable solar to **support grid reliability** and pair with storage to provide new options for **community resilience.**

Provide **relevant and objective technical information** on solar technologies to stakeholders and decision-makers.

How does SETO decide which topics to fund?

STARTING POINT: MULTI-YEAR PROGRAM PLAN

RESEARCH, ANALYSIS, AND LITERATURE

CONGRESSIONAL AND ADMINISTRATIVE DIRECTION

WORKSHOPS, CONFERENCES, AND EVENTS

PEER REVIEW

REQUESTS FOR INFORMATION (RFIS)

ACTIVE PROGRAM MANAGEMENT AND SETO STAFF "IDEA-FESTS"

TOPICS REVIEWED BY DOE LEADERSHIP AND OTHER DOE OFFICES

Funding Restrictions

- SETO cannot or does not:
  - Fund development of policy at a local, state, or federal level
  - Fund advocacy work
  - Fund passive solar or solar hot water projects
  - Purchase solar systems for individuals or other entities
  - Provide loans for solar technology demonstrations
  - Provide grants upon request
  - Seek out entities to fund

Tools and strategies beyond direct funding activities

Laying out long-term vision, goals and thought leadership across elements of the value chain to proactively drive innovation

Examining novel ideas, asking interesting questions, and looking at broad range of potential values, costs and benefits beyond profit.

Producing free, accessible analysis, increasing market transparency, and providing validation without advocacy

Fostering connections and building communities though programs and convening

Reaching stakeholders beyond the solar industry

Annual Budget Process

1. SETO drafts a budget request or "Congressional Justification", DOE conducts internal review
2. President's Office of Management and Budget works with DOE to align with administration priorities
3. President submits budget request to Congress
4. Lawmakers create their own budget plans with spending levels and pass a "Budget Resolution"
5. House and Senate committees set funding for each program through appropriations bills*
6. House and Senate resolve differences and finalize "Committee Report Language"
7. Budget returns to the President for signature to become law
8. Agencies carry out work consistent with existing authorizations, plans and appropriations

* A "Continuing Resolution" may be passed for a few months or for years to keep budget levels and appropriation language the same as a prior year rather than creating new appropriations levels and guidance

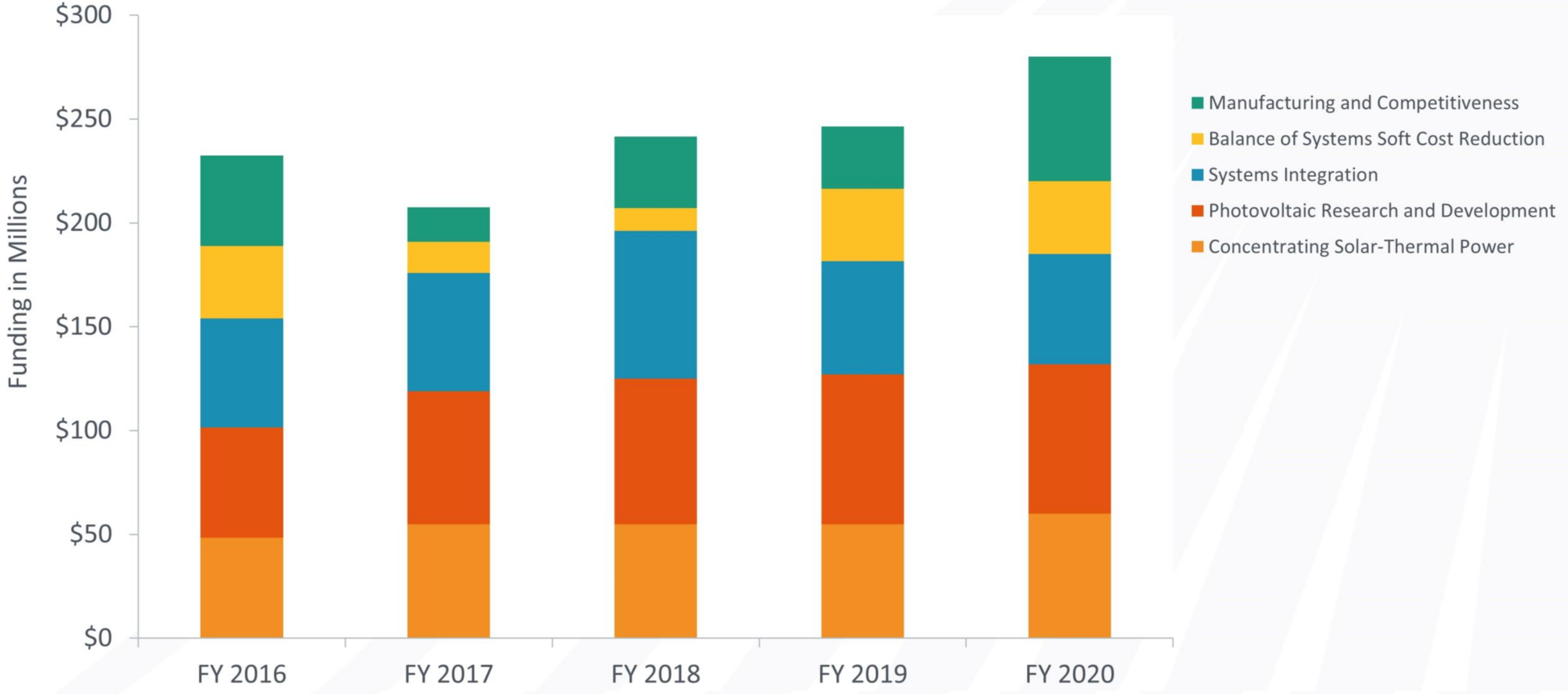
Congressional Budget Direction

	HOUSE	SENATE	CONFERENCE
	Total Recommendation: $270,000,000	Total Recommendation: $260,000,000	Total Recommendation: $280,000,000
Photovoltaics	• Recommends not less than $72,000,000 for Photovoltaic Research and Development to develop new or improved high-performance photovoltaic modules and architectures, and to achieve greater than 40 percent cell efficiencies.	• The Committee recommends $70,000,000 for Photovoltaic Research and Development to develop new or improved high-performance cell materials and architectures and achieve greater than 40-percent cell efficiencies. The Department is encouraged to cooperate with industry and academia in its research and development efforts.	• The agreement provides $72,000,000 for Photovoltaic research & development.

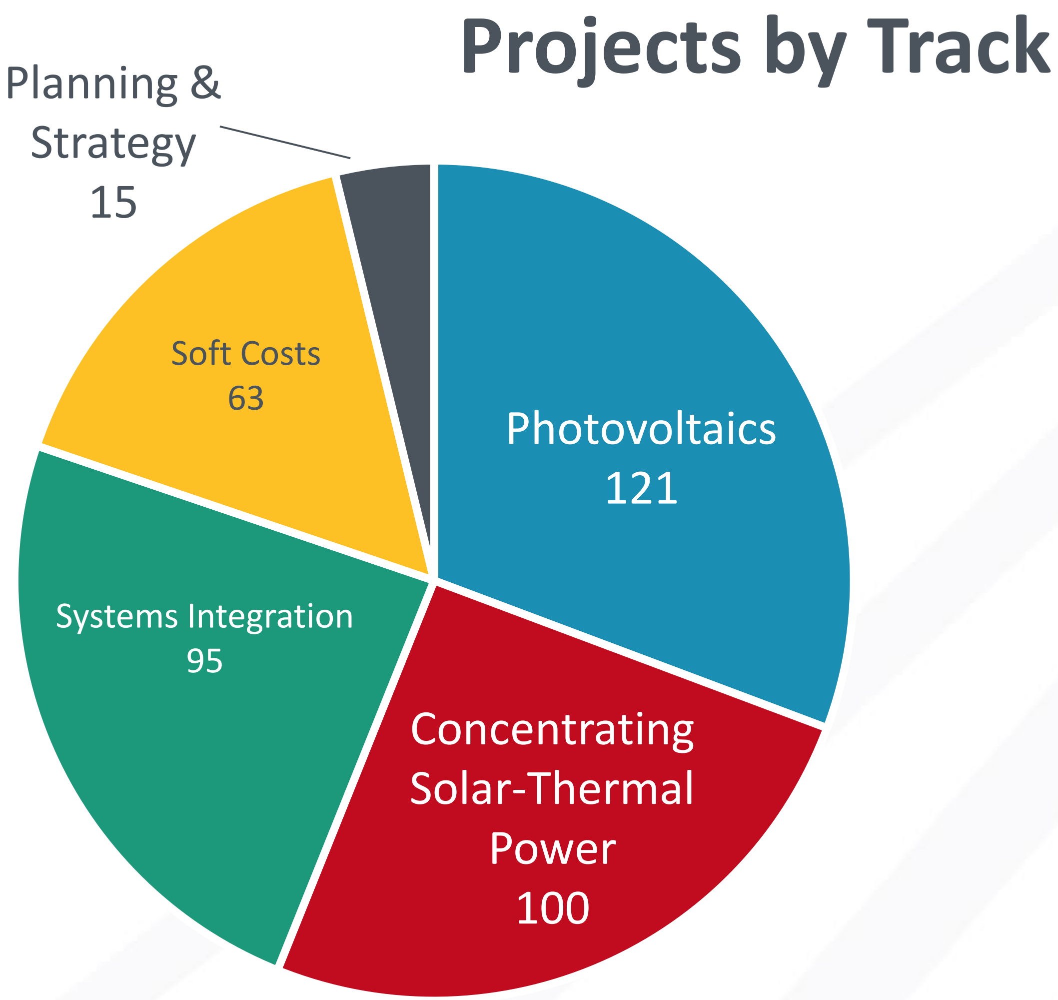
Directed programming and planning variations

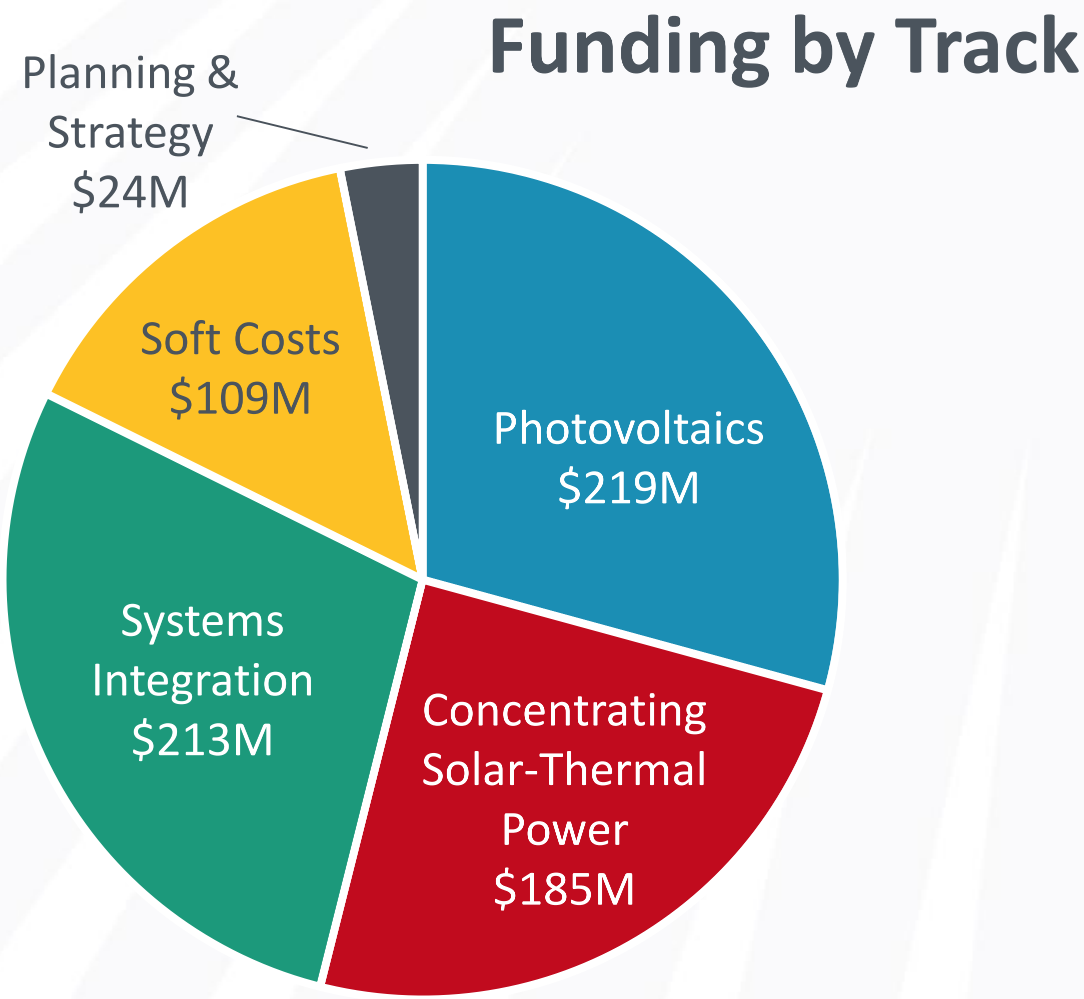
Systems Integration	• Recommends not less than $49,500,000 for Systems Integration.	• Recommends $40,000,000 for Systems Integration and encourages the Department to address the technical barriers to increased solar penetration on the grid, including grid reliability, dispatchability, power electronics, and communications.	• The agreement provides $50,000,000 for Systems Integration.
Innovations in Manufacturing	• Recommends not less than **$30,000**,000 for Innovations in Manufacturing Competitiveness.	• Recommends **$35,000**,000 for Innovations is Manufacturing Competitiveness.	• The agreement provides **$60,000,000** for Innovations in Manufacturing Competitiveness.
Floating Solar Technologies	[No direction]	• **Within available funds, the Committee recommends $1,500,000 for competitively selected projects focused on floating solar powered aeration systems**	**[Senate language stands]**

SETO Congressional Budget Overview



Breakdown of Projects and Funding by Track





STRATEGIC EFFORTS

Market Analysis

Scenario Planning & Technical Analysis

Data & Models

Collaborations & Special Projects

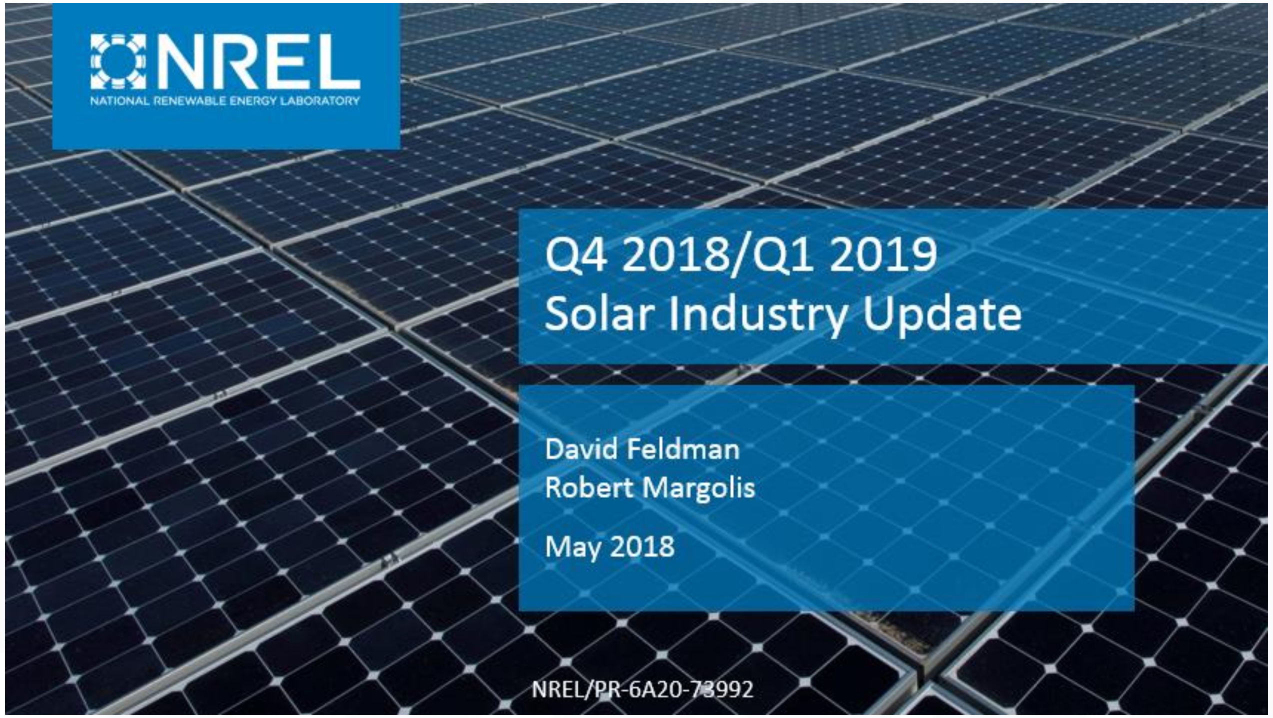
Market Analysis

30348	LBNL	Aligning Utility and Solar Interests: Utility Regulation and Planning for a SunShot Future
34158	LBNL	Solar Market Data Tracking and Analysis
34271	NREL	Strategic and Programmatic Analysis to Support DOE
34170	LBNL	Solar-to-Grid (S2G): Analytic Support to Inform Reliability, Market Value, and Affordability

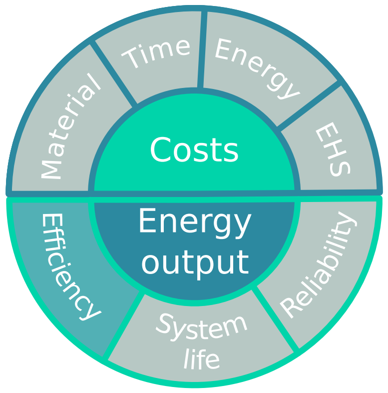
Industry tracking examples

Agenda

1. Global Solar Deployment
2. U.S. PV Deployment
3. PV System Pricing
4. Global Manufacturing
5. Component Pricing
6. Market Activity
7. Opportunity Zones



III-V's - What are the challenges?



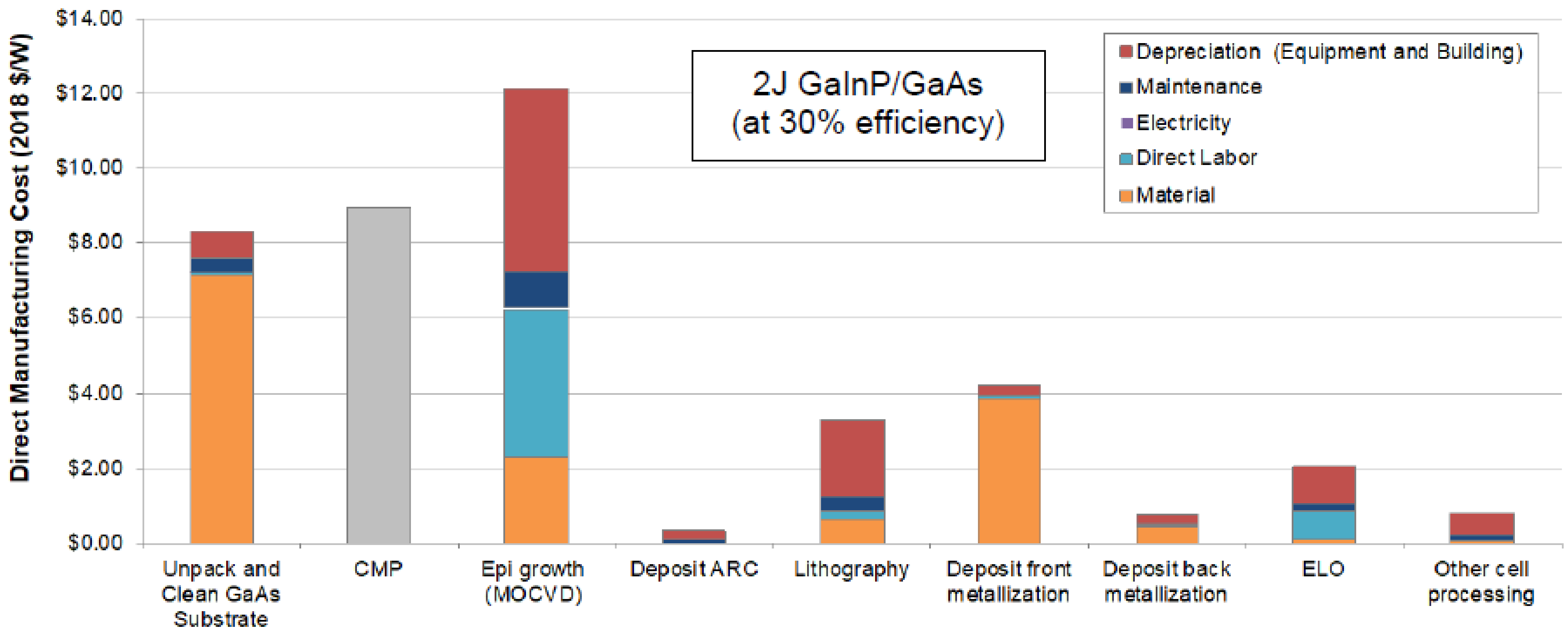


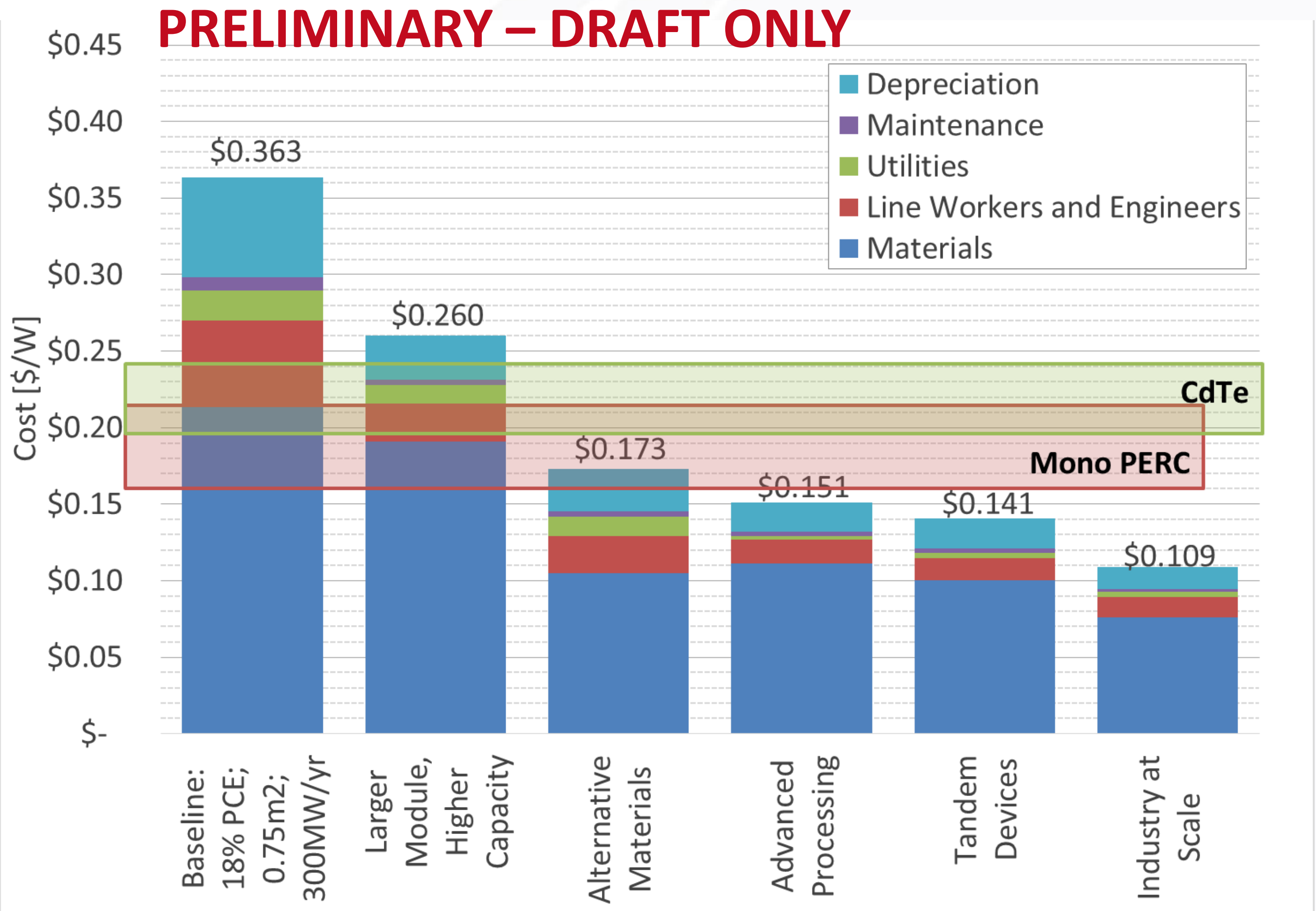
Figure 7. Step-by-step cost breakdown for (top) single junction GaAs solar cells at 28% efficiency and (bottom) 2J GaInP/GaAs solar cells at 30% fabricated via MOCVD in the base case

Assumes U.S. manufacturing at 3,800 cells/month (170kW/year - 182kW/year, depending on the efficiency); the CMP bar is gray because we do not have a bottom-up CMP cost model, but rather total costs obtained via industry interviews.

Perovskites: Motivation for R&D Program:

Production Cost Estimates:

- Multiple progressions based on current areas of R&D
- No fundamental material or process changes
- Conservative economies of scale estimates

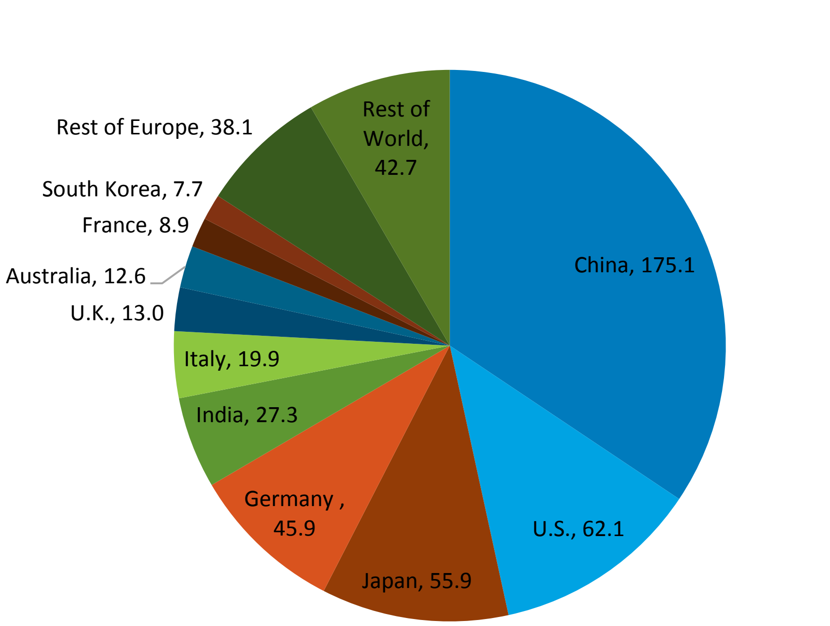


Opportunities in Perovskite Technology Progressions.
Dawson, A., Woodhouse, M., Tinker, L. – To be submitted

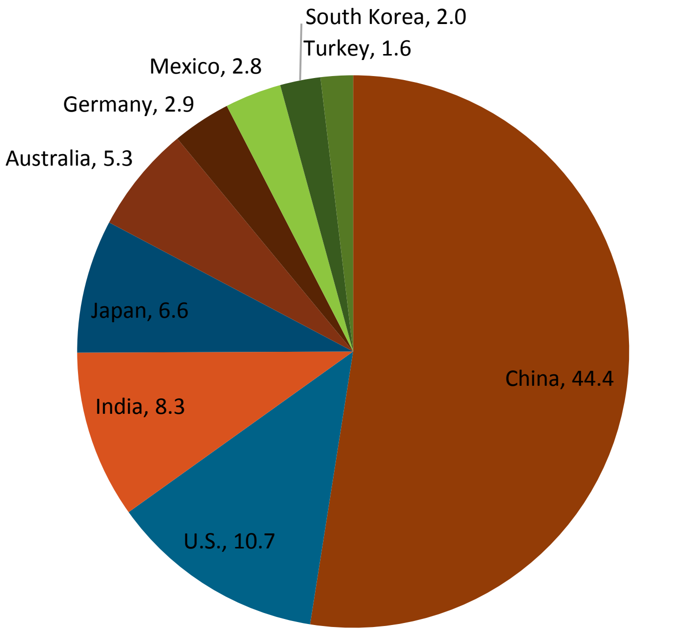
Top PV Markets

- At the end of 2018, global PV installations reached 509 GW-DC, an annual increase of 102 GW-DC from 2017.
- The leading five markets, in cumulative and annual PV installations at the end of 2018 were China, India, the United States, Japan, and Europe.
- By the end of 2018, China had more than 175 GW of cumulative PV installations, an annual increase of 44 GW—less than the 53 GW China installed in 2017; however, still more than the other top nine markets combined.
- In 2018, the U.S. PV market was the second-largest market in terms of both cumulatively and annual installations.

Cumulative PV Deployment—2018 (509 GW-DC)



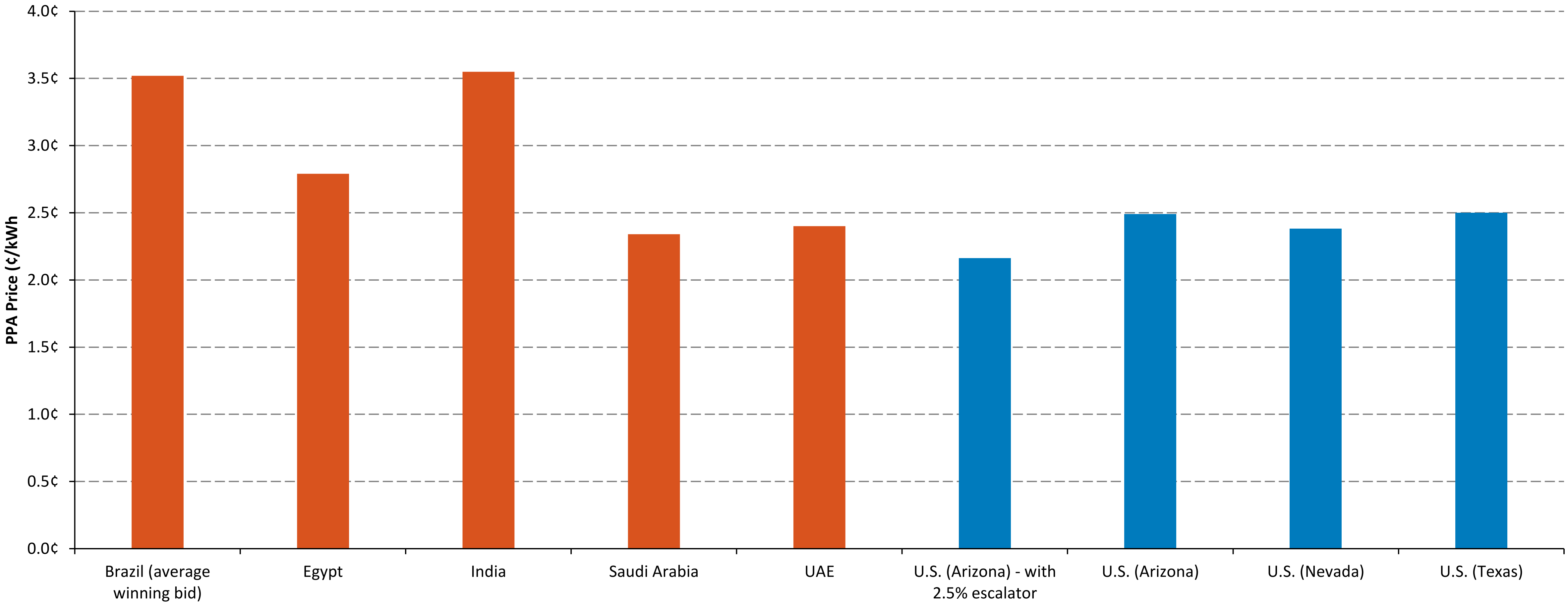
Annual PV Deployment—2018 (102 GW-DC)



Source: : Solar Power Europe “Global Market Outlook For Solar Power / 2019 – 2023”

Selection of Lowest Solar Auction Bids around the World In 2018

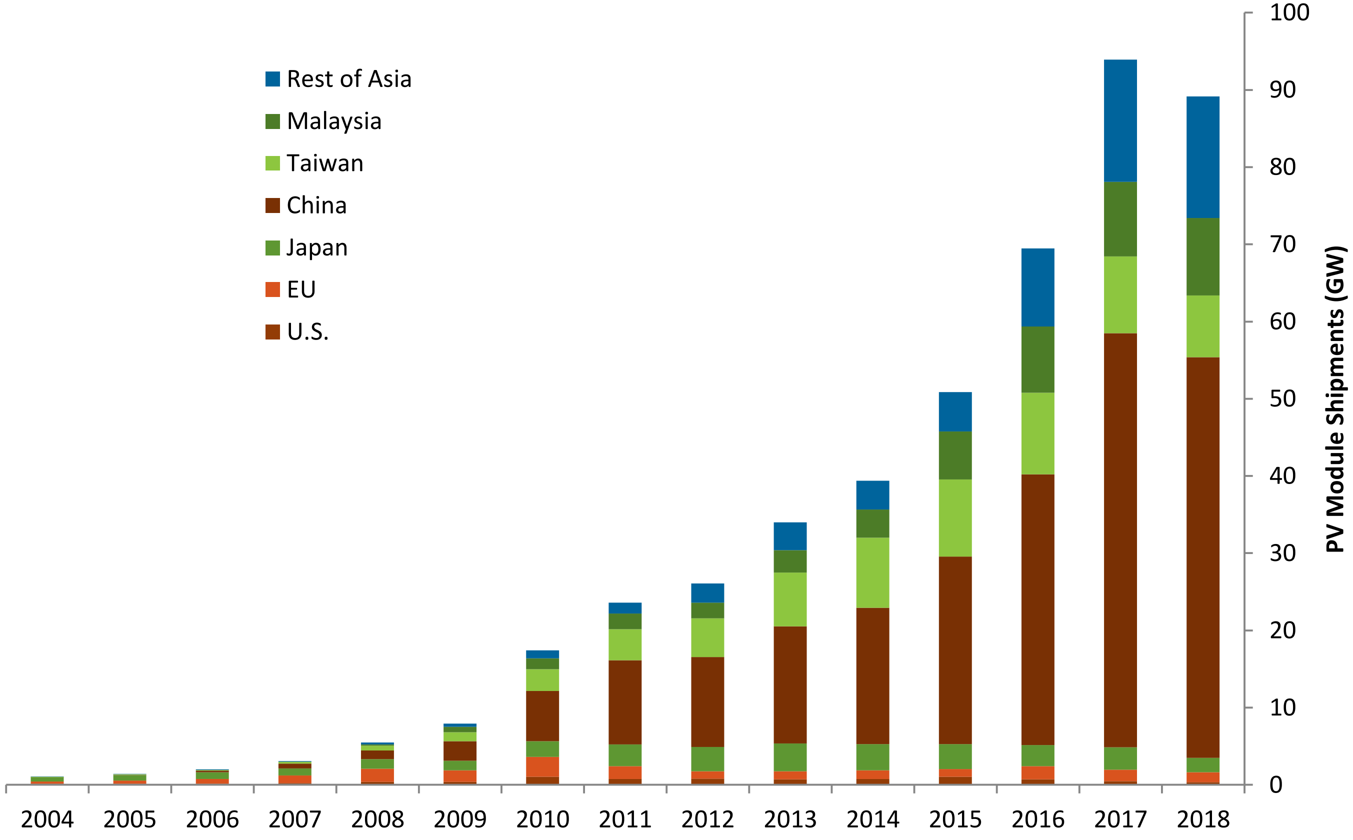
- While global solar auction bids varied around the world, several countries, including the United States, saw solar project bids between 2.1¢/kWh AND 3.5¢/kWh in 2018.
  - Some of these bids included escalators or incentives (e.g., the U.S. Investment Tax Credit).



Source: Solar Power Europe "Global Market Outlook For Solar Power / 2019 – 2023"

Global Annual PV Shipments by Region*

- In 2018, global PV shipments were approximately 89 GW—a decrease of 5% from 2017.

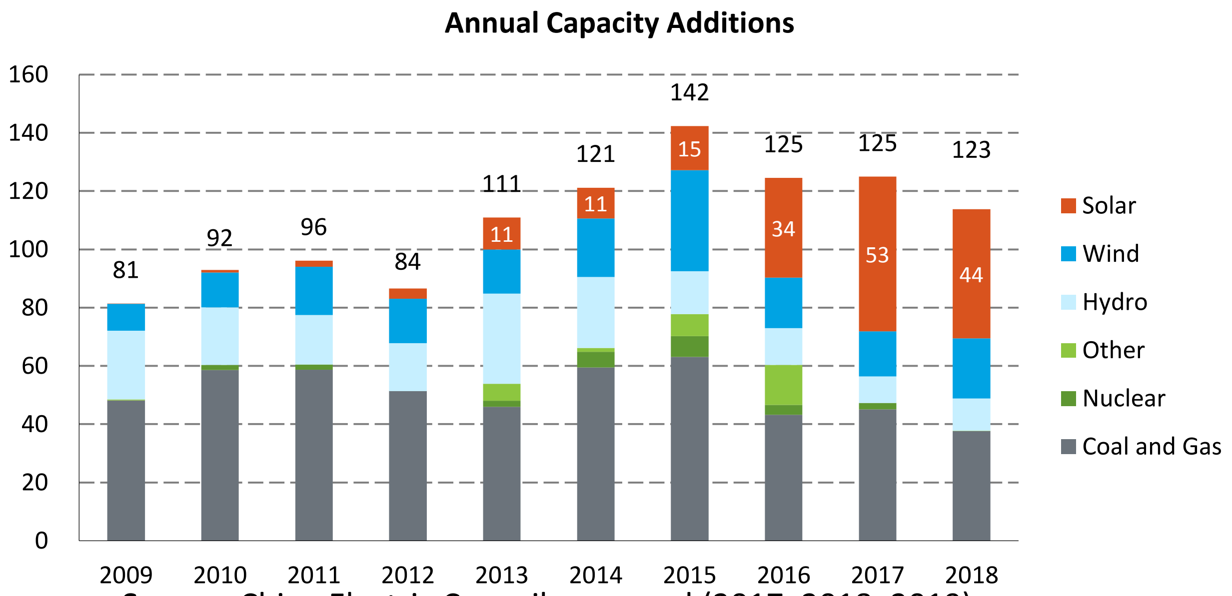


***Note:** Excludes inventory sales and outsourcing.
Source: 2004-2018: Paula Mints. "Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2018/2019." SPV Market Research. Report SPV-Supply6. April 2019.

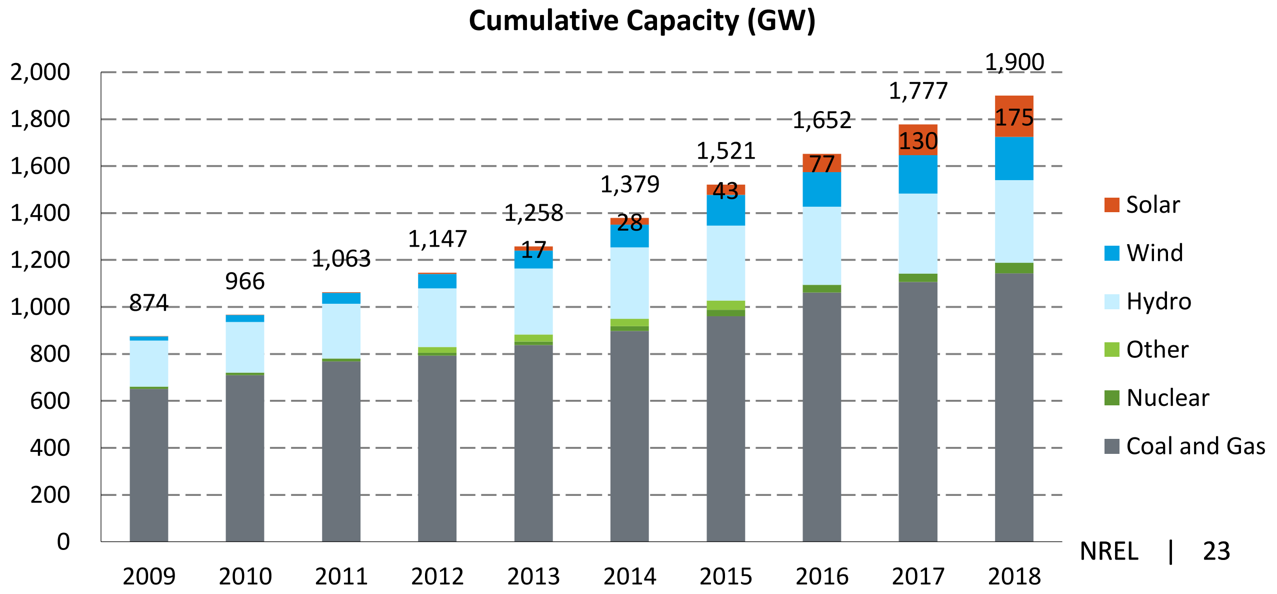
- 2018 is the first time since before 1976 that PV shipments declined, y/y, caused by Chinese pullback in demand.
  - Because China represents approximately 50% of supply and demand, the market is far more susceptible to shocks.
- 98% of the PV shipments came from Asian countries, with China supplying 57%.
- The pullback was not uniform across all markets, as Chinese shipments only shrank 3% and Malaysian shipments actually grew 4%.
  - Japan produced fewer PV modules and cells in 2018 than it did before the FiT, with a 35% reduction y/y due to price pressure.
  - Europe is also producing less, due in part to the elimination of the minimum pricing agreement with China.
  - U.S. market share was 0.41% in 2018, its lowest level to date; however, it is expected to bounce back in 2019.

Chinese Generation Capacity Additions by Source

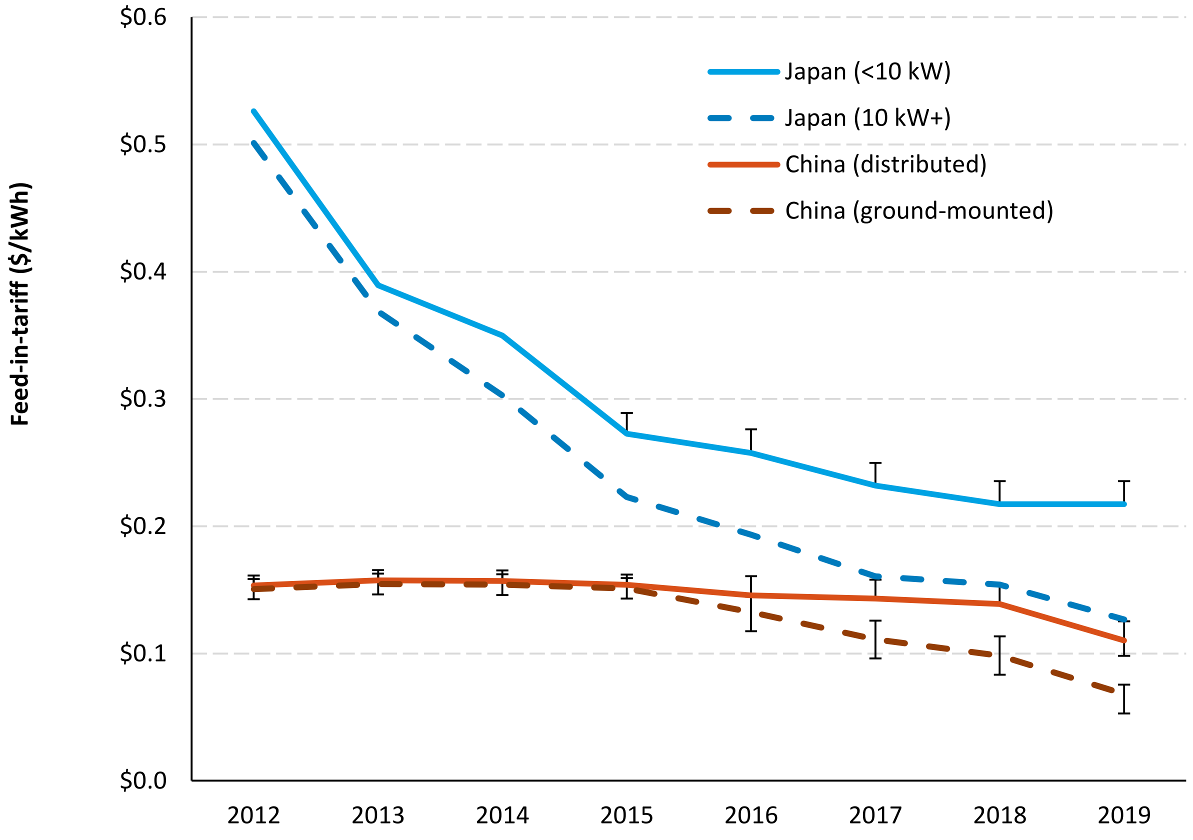
- In 2018, solar contributed 36% to new generation capacity in China (44 GW; 23 GW were utility-scale and 21 GW were distributed PV) and 9% of cumulative capacity (175 GW).
  - 2018 was the second straight year that wind and solar contributed more than half of all new electric generation in China (53%).
  - Chinese annual electric generation capacity additions have been around 4–6 times greater than additions by the United States for the past 10 years.
- As China grows its electricity infrastructure, it has rapidly incorporated non-carbon sources of electricity generation.
  - Since 2009, China has doubled its installed electric generation capacity, and at the same time reduced the percentage of total coal and gas capacity from 74% to 60%.
  - From 2010 to 2018, non-carbon generation capacity as a percentage of total new capacity increased from 37% to 69%.



Source: China Electric Council, accessed (2017, 2018, 2019).



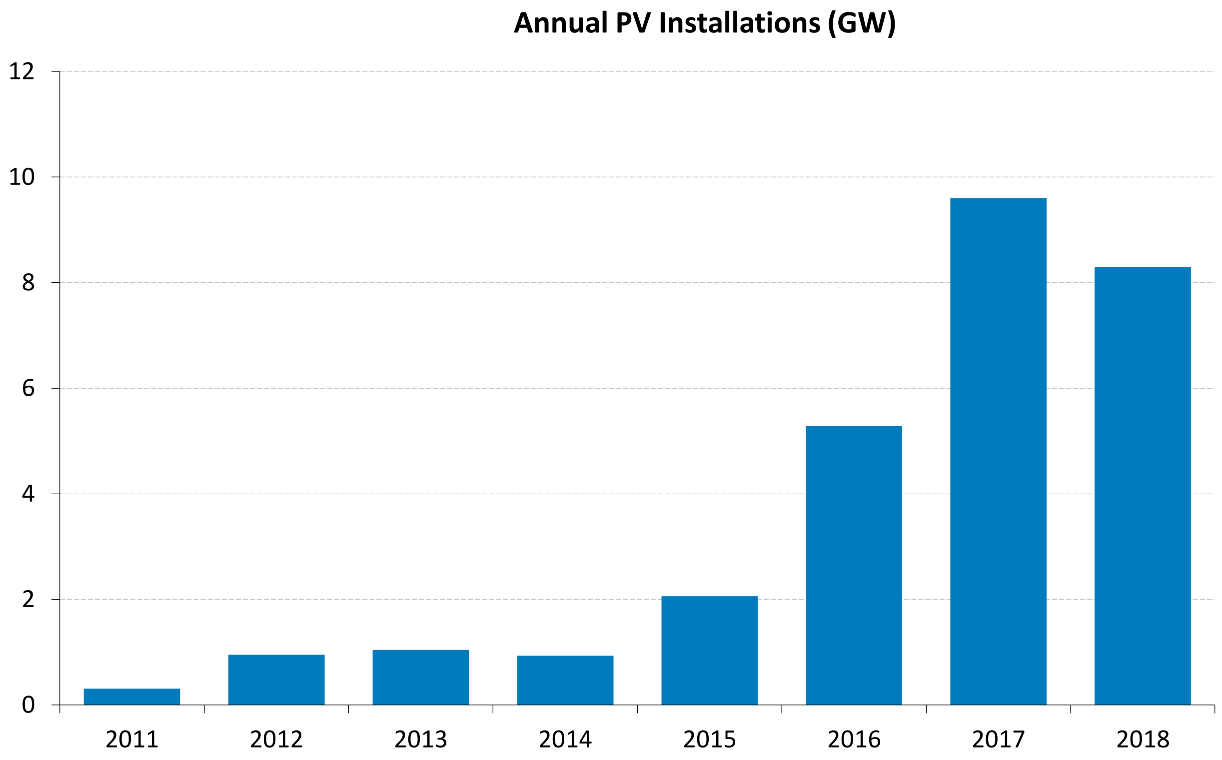
Japanese and Chinese Feed-in-Tariffs



- Since 2012, Japanese FiT rates have declined 65% for systems greater than 10 kW and 43% for systems fewer than 10 kW.
- Despite the rapid decline rates, Japanese FiTs are still double that of Chinese FiT rates, which also declined between 43% and 57% (depending on geography and market segment) over the same period.
- In 2017, Japan began competitively awarding tariffs to PV systems above 2 MW in size.
  – Next year, it will begin doing the same for systems greater than 500 kW.
- Beginning in 2019, China will also award FiT payments “subject to competition.”

Sources: BNEF, IEA, U.S. Department of Trade, Federal Reserve, PV Magazine (05/01/19).

Indian Market Update

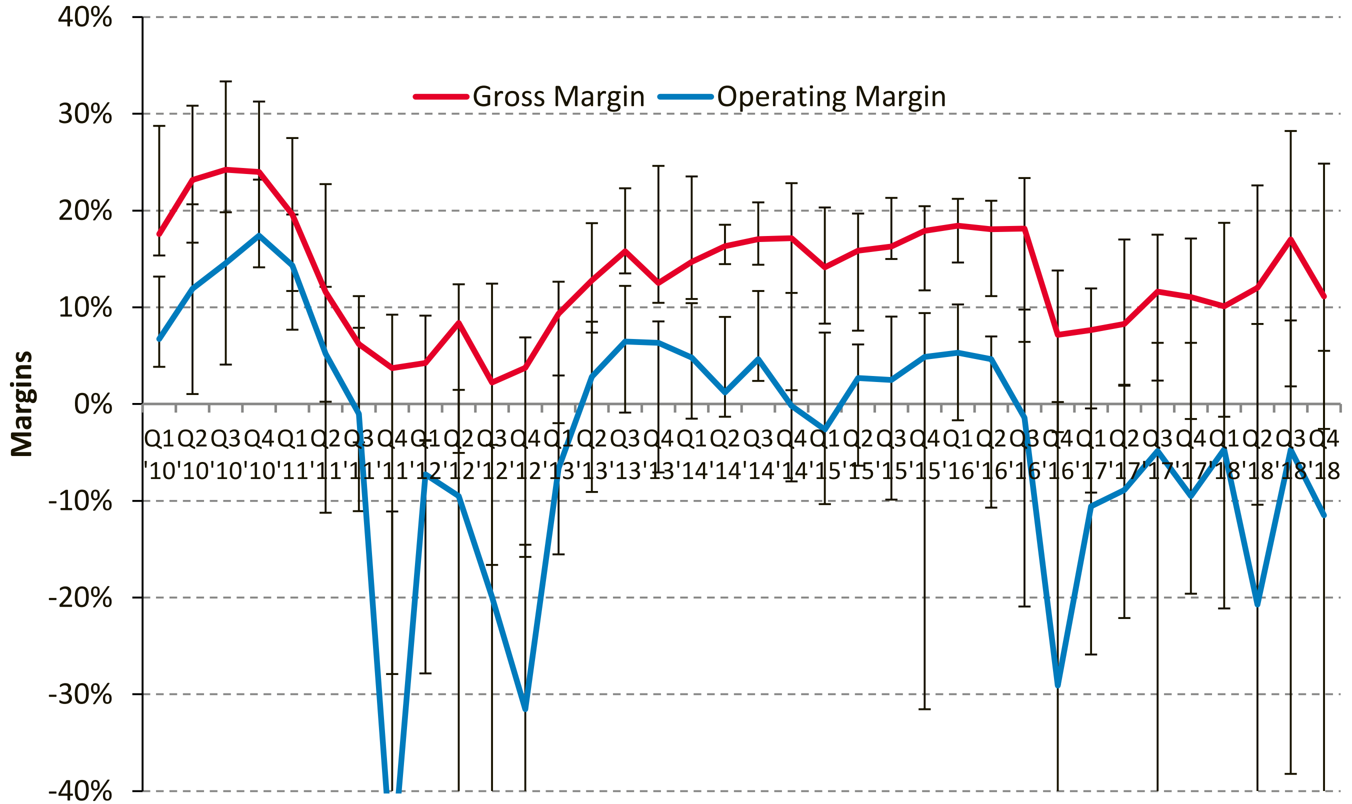


India installed 8.3 GW in 2018, down from its peak of 9.6 GW in 2017.

- The National Solar Energy Federation of India expects India to rebound in 2019 with 13 GW.
- In 2018, 74% of India's new power generation came from renewables, with solar contributing 50%.
- India has targeted 100 GW of solar installations by 2022; at the end of 2018, there were 28 GW.
- The Indian government is also in the process of establishing 66 GW of transmission line capacity by March 2020 to help bolster solar growth.

Source: Solar Power Europe "Global Market Outlook For Solar Power / 2019 – 2023." BNEF, "1H 2019 India Market Outlook." January 2019. BNEF, "Capacity & Generation" data set. Accessed May 5, 2019.

PV Manufacturers' Margins



Line represents the median, with error bars representing 80th and 20th percentiles for the following companies in Q4 2018: Canadian Solar, First Solar, Hareon Solar, HT-SAAE, Jinko Solar, LONGi, Motech Industries, Neo Solar Power, ReneSola, and SunPower. Margin data from Hanwha Q Cells, JA Solar, Trina, and Yingli are also included from Q1 2010 to Q3 2018 where available.

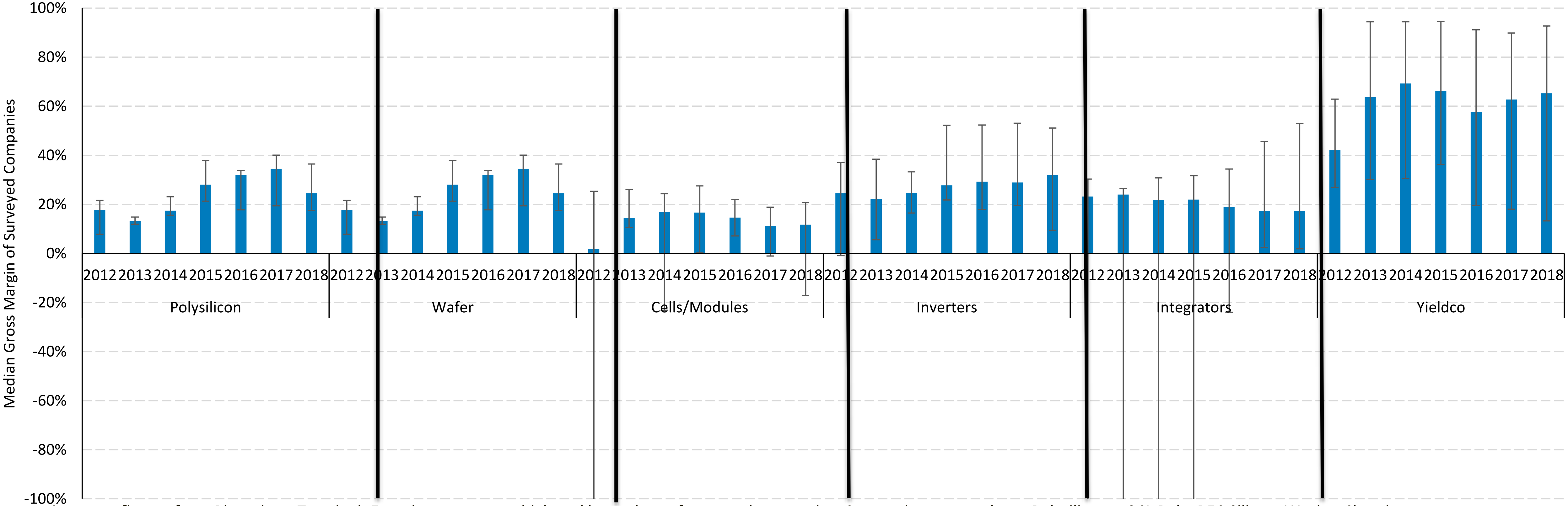
Performance of solar companies declined, on average, in Q4 2018, as ASP of modules and cells fell.

Sources: Company figures based on data from Bloomberg Terminal and SEC filings by the respective companies.

Gross Margin across Supply Chain

- Polysilicon and wafer manufacturers generally had lower gross margins between 2017 and 2018, while module and cell manufacturers' gross margins were relatively flat, y/y, after falling from 2014 to 2017.

- In 2018, gross margins were mixed in the PV industry, with variations by sector and within each sector.

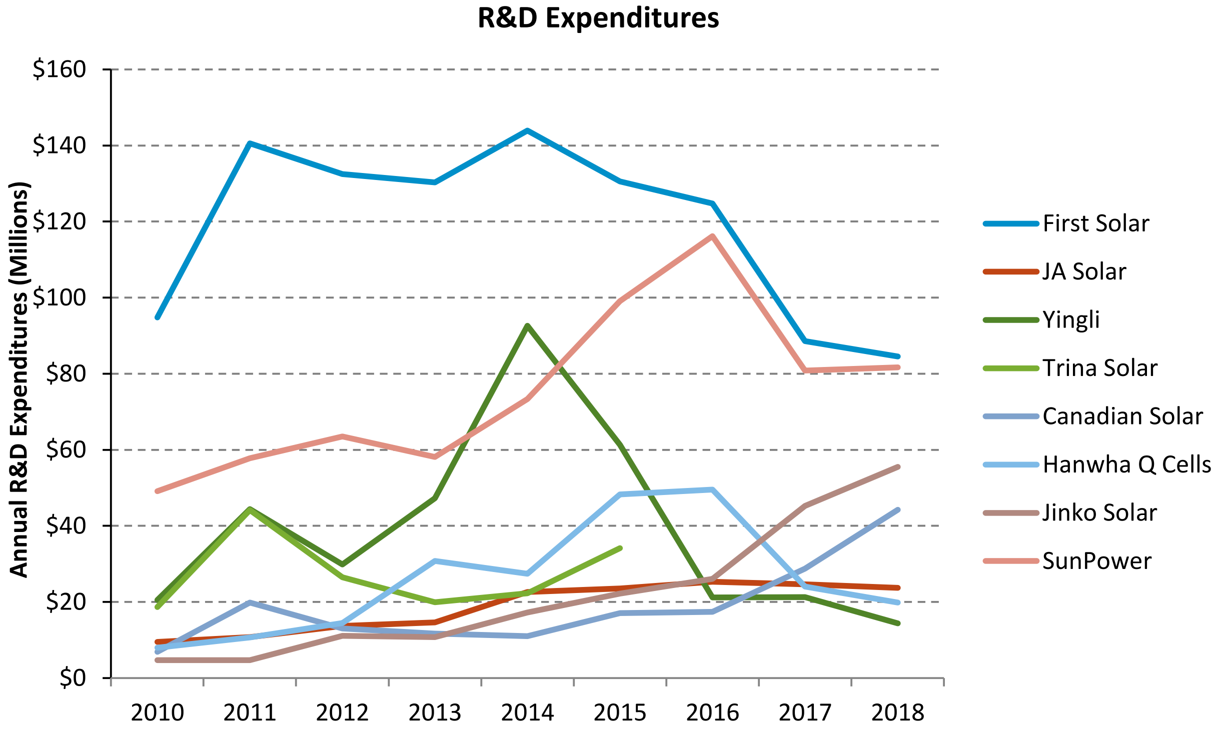


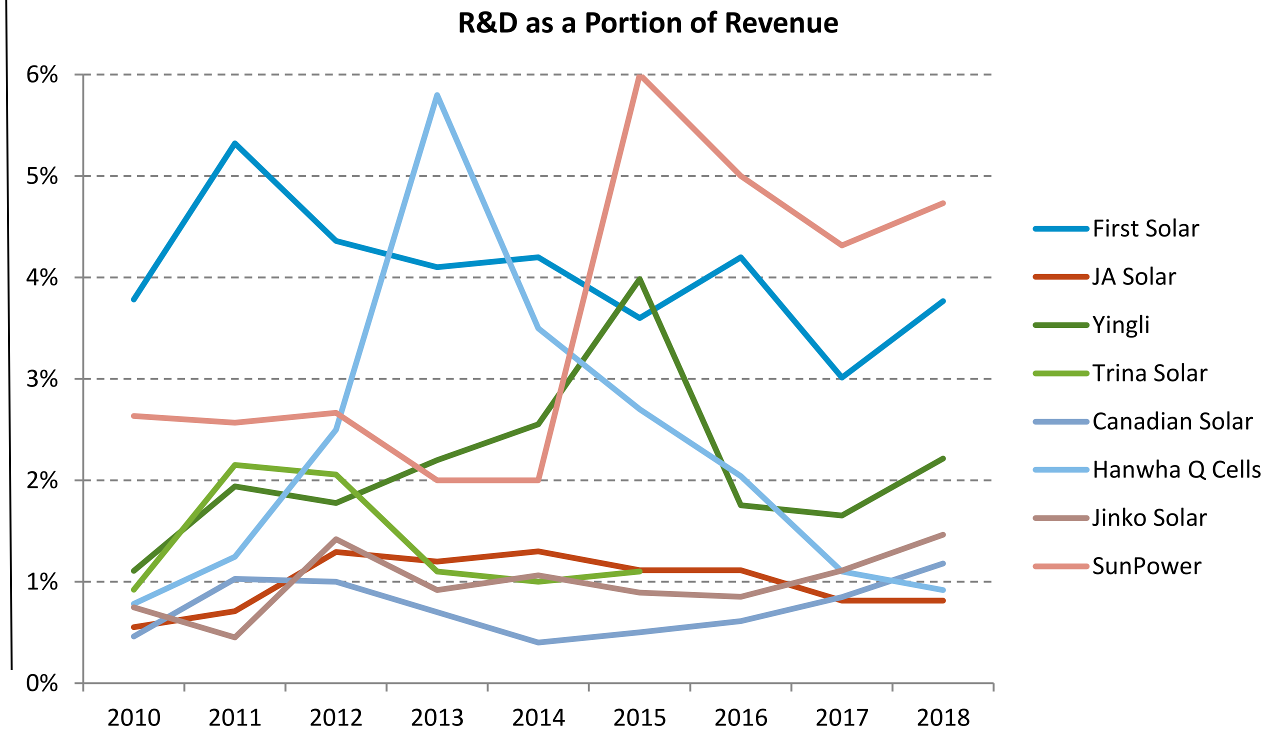
Sources: Company figures from Bloomberg Terminal. Error bars represent high and low values of surveyed companies. Companies surveyed are: Polysilicon – GCL Poly, REC Silicon, Wacker Chemie, Ferroglobe; Wafers - ReneSola, Wafer Works Corp, Danen Technology Group, Green Energy Technology Inc; Cells/Modules, Gintech, Motech, First Solar, JA Solar, Yingli, Trina Solar, Canadian Solar, PV Crystalox Solar, Hanwha Solar One, Jinko Solar, SunPower; Inverters – SolarEdge; Enphase; SMA Solar; Advanced Energy Industries; Integrators - Real Goods Solar; SolarCity (through 2015); Vivint Solar; Sunrun; Sunworks; Enlight Renewable Energy; IPP/Yieldco - Brookfield Renewable Partners; Algonquin Power & Utilities Corp; NextEra Energy Partners' Northland Power; Pattern Energy; Terraform Power; TransAlta Renewables.

Research and Development

- First Solar continues to lead in R&D spending, although SunPower is a close second. Both companies' 2018 R&D funding are significantly below that of their peak years.
- Canadian Solar and Jinko Solar have significantly increased their R&D budgets, growing 3X and 4X from 2013 to 2018.

- R&D among the tracked companies increased 3% to $324 million in 2018.
  – The tracked companies shipped approximately 26 GW in 2018—approximately 29% of global shipments. If the rest of the industry spent similar levels in R&D, PV manufacturers would have spent $1 billion on R&D in 2018.

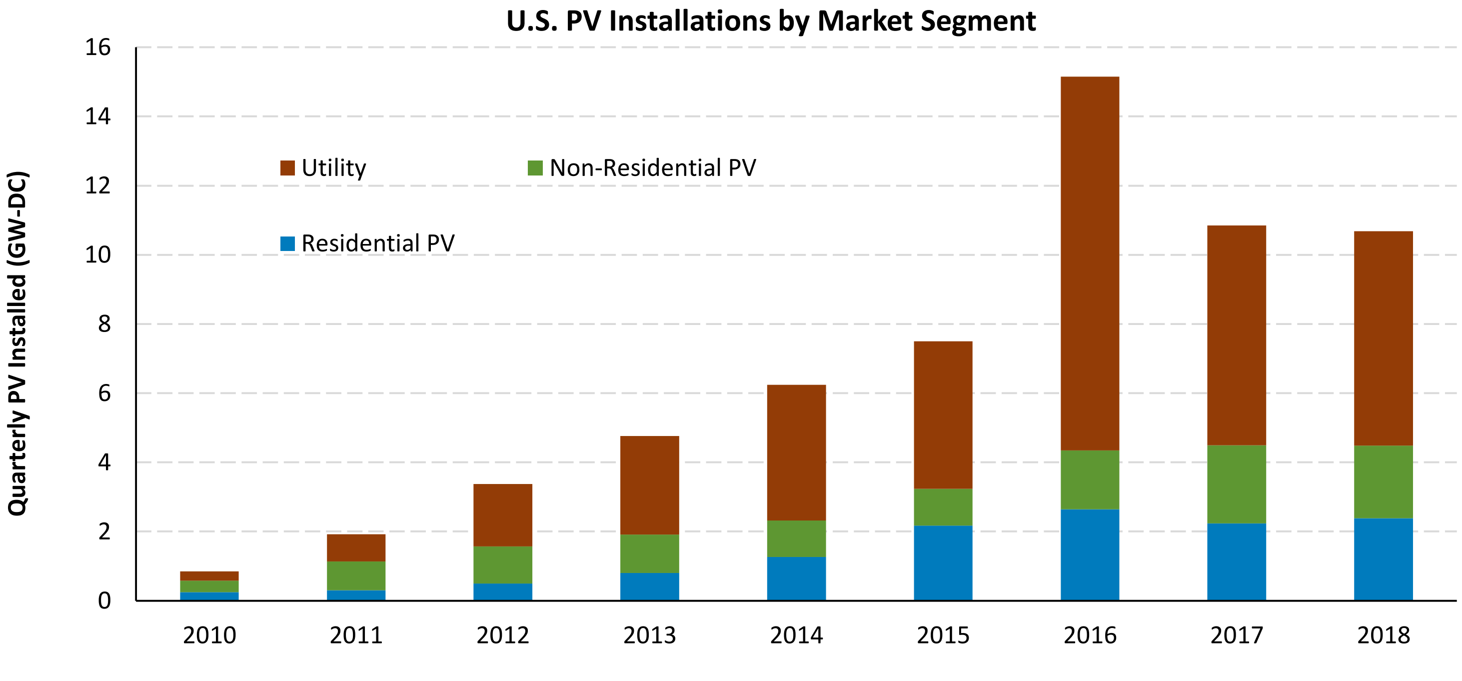


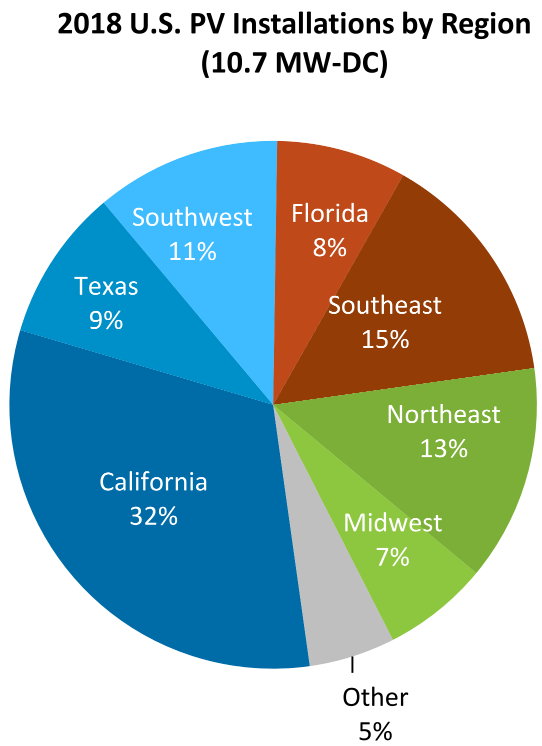


Sources: Company figures based on Q4 2018 (and previous) SEC filings by the respective companies.

U.S. Installation Breakdown

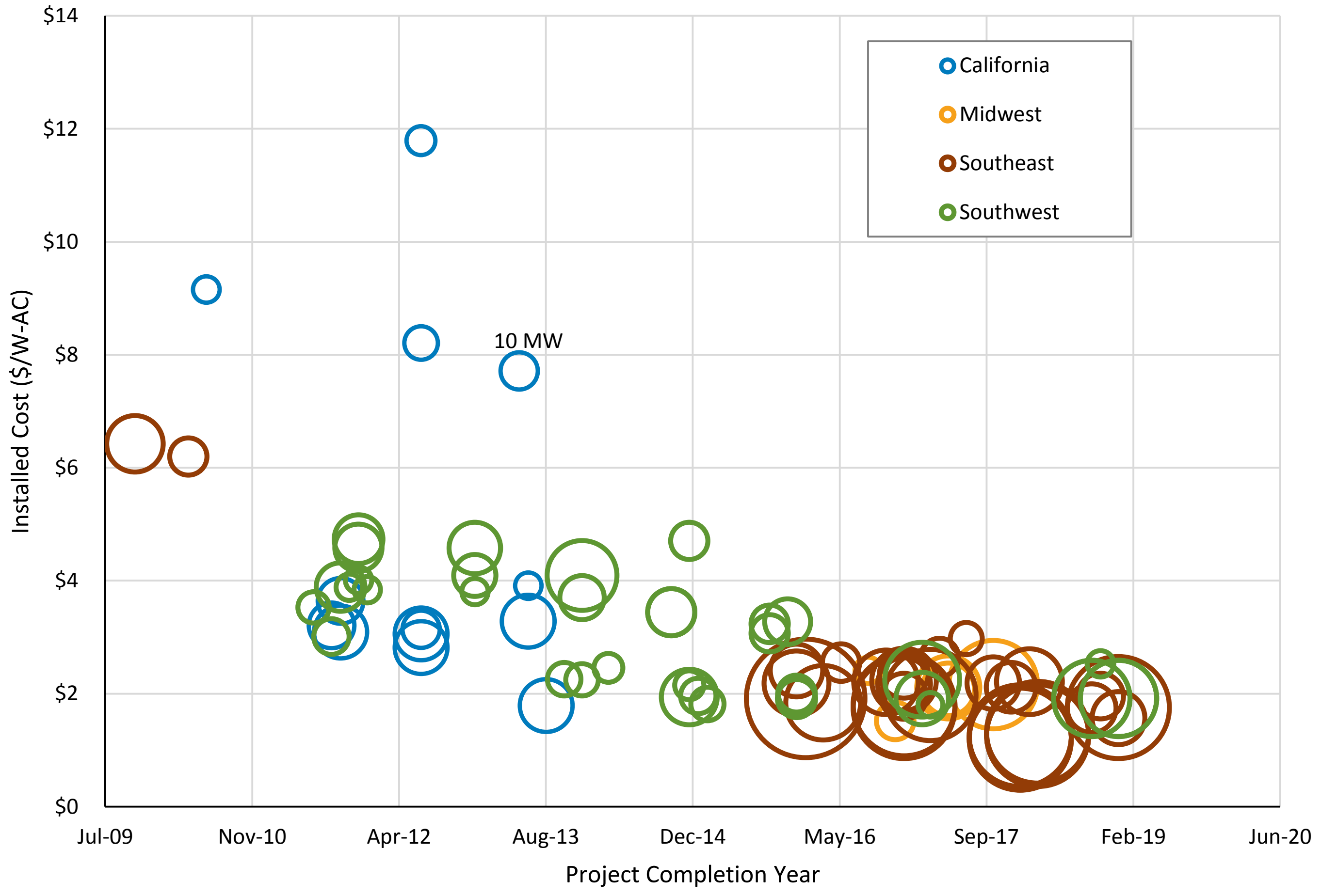
- The United States installed 10.7 GW-DC of PV in 2018, 4.2 GW-DC in Q4, and cumulative capacity reached 62.5 GW.
  - 2018 U.S. PV installations were down 2%, y/y, with the residential market growing 7%, but the nonresidential and utility-scale markets contracting 7% and 2% respectively.
- In 2018, new PV installations have had a fair geographic mix across the United States, though most capacity was installed in southern states.





Sources: Wood Mackenzie/SEIA: U.S. Solar Market Insight 2018 Year-in-Review.

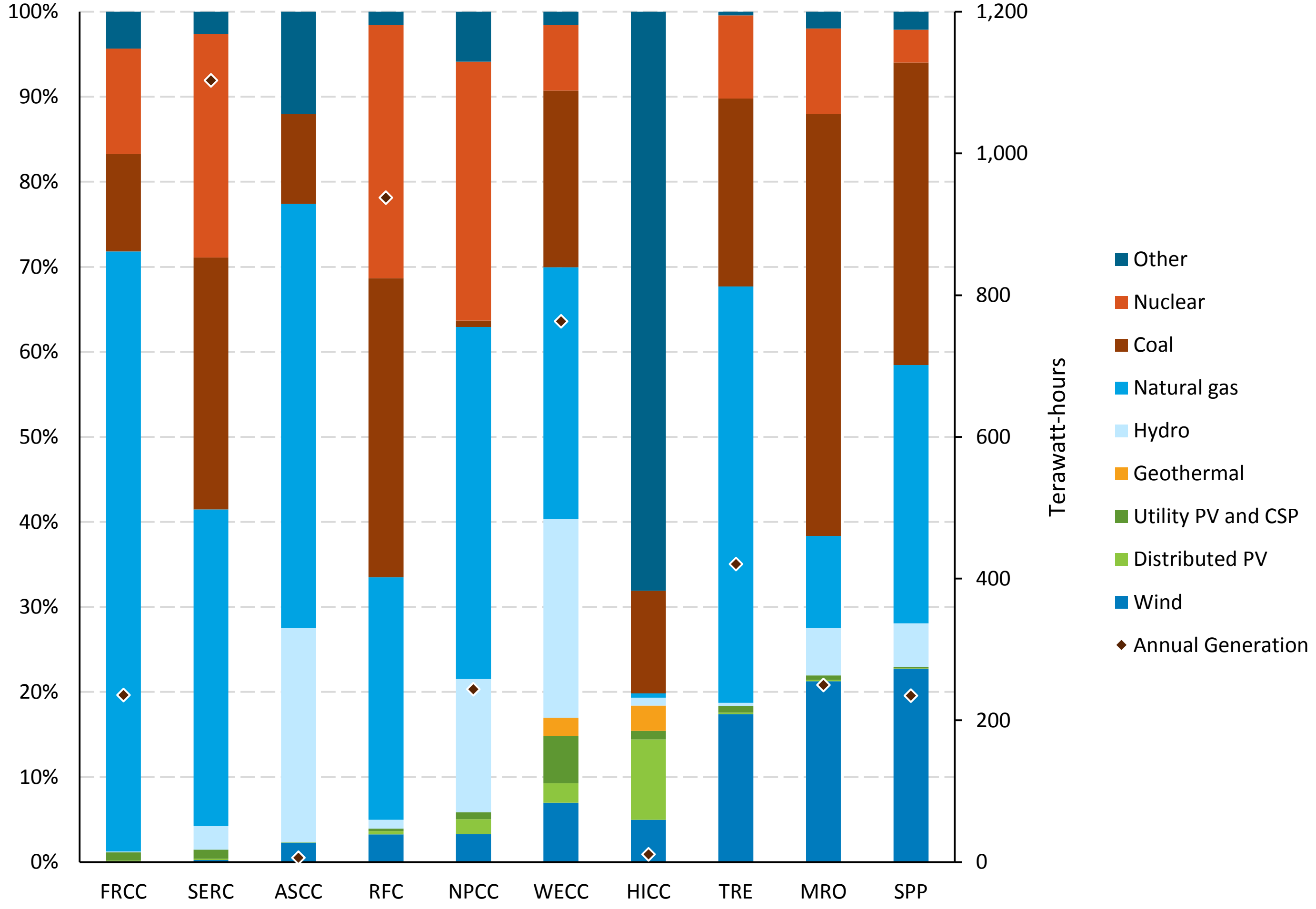
Utility-Owned PV Pricing (>5 MW)



- In a select data set of utility-scale PV systems (92 projects totaling 2.4 GW-AC) owned by 19 regulated utilities, the average system size has trended upwards as system pricing has trended downwards.
  - The average system size in this data set was 8 MW in 2010 and 51 MW in 2018.
- Some of the reductions in price may be explained by a change in geographical focus over time.
  - Of the systems in this data set, 64% by capacity, are in the Southeast, with most installations happening after 2015.
  - However, virtually all areas of the country show a significant reduction in price over time.

Sources: FERC Form 1 filings from the from the following utilities: Alabama Power, Allete, Arizona Public Service, Avangrid, DTE, Duke Energy, El Paso Electric, Florida Power and Light, Georgia Power, Indiana Michigan Power, Kentucky Utilities, Nevada Power, Pacific Gas and Electric, Public Service of New Mexico, Southern California Edison, Tampa Electric, Tucson Electric, United Illuminating, UNS Electric, Virginia Electric.

2018 Generation Mix by NERC Region



- Currently, solar and wind represent a range of each NERC region's electricity, varying from approximately 1% to 23%.
- In 2018, the majority of electricity generated by solar (62%) occurred in WECC, representing approximately 8% of all electricity generated in that area.
  - However, Hawaii generated a higher percentage (10%) of its generation from solar.
  - Solar and wind together represented 15% of 2018 WECC electricity generation and all renewables represented approximately 40%.
- SPP lead all NERC regions with 23% of its electricity from variable generation in 2018 (all wind).

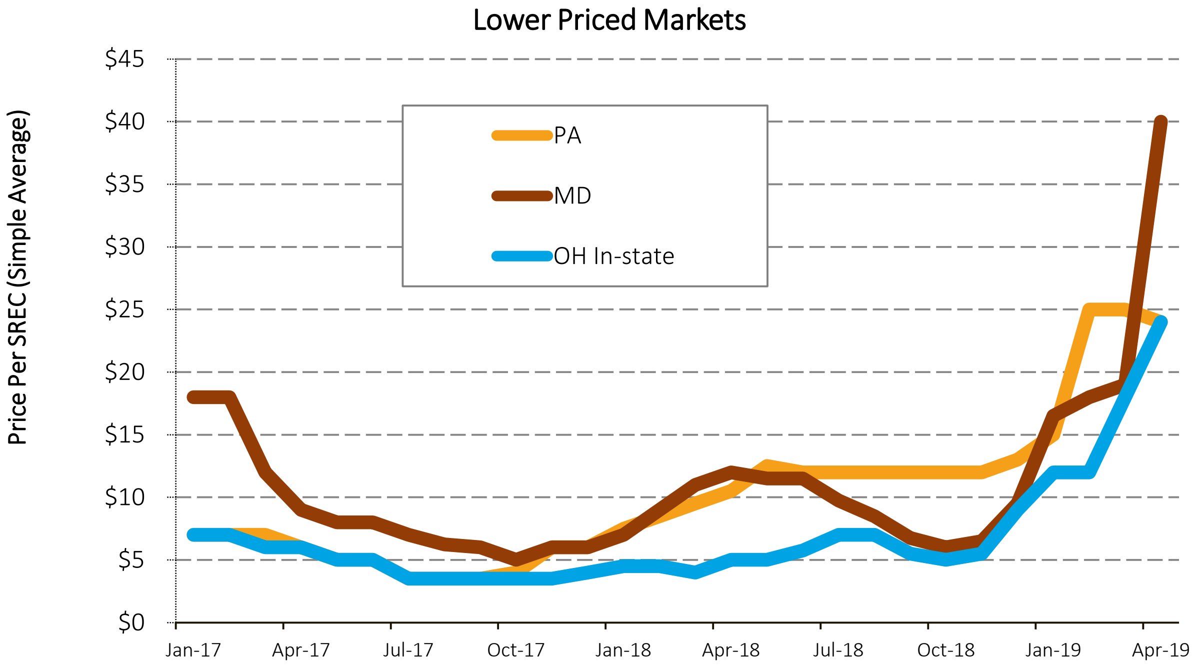
Note: All numbers are approximate and only include U.S. generation. EIA monthly data for 2018 are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore, a certain amount of solar data has not yet been reported. EIA-923 data does not include NERC classification for a significant portion of solar, and other, generating facilities designated as "State-Fuel Level Increment"; for these systems, we approximated the NERC region using state designation. NERC regions do not strictly follow state lines, so best estimates were made in NERC designations for states. We also used these state categorizations to designate distributed PV generation to NERC regions.

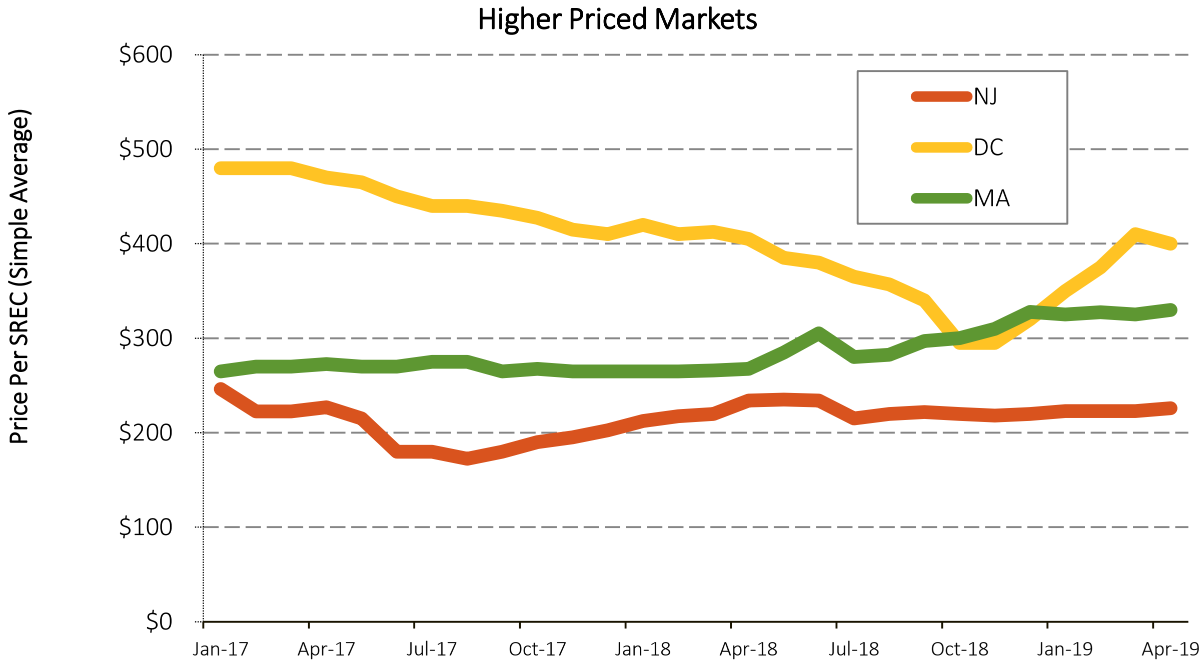
Sources: U.S. Energy Information Administration, EIA-923; distributed PV (EIA "Electric Power Monthly").

SREC Pricing

- SREC pricing continued to rise in all markets in the beginning of 2019.
  - Some of these markets are in undersupply, but many have been buoyed by proposed or enacted legislation, raising RPSs.

- The largest increases in pricing occurred in Maryland and Pennsylvania.
  - In April, Maryland doubled its RPS to 50%, and increased the solar carve out to 5.5% in 2019 and 14.5% to 2028.
  - In November, the Pennsylvania Department of Environmental Protection released strategies to get 10% of its electricity from solar by 2030; in April, the governor announced his support of a senate bill to do the same.

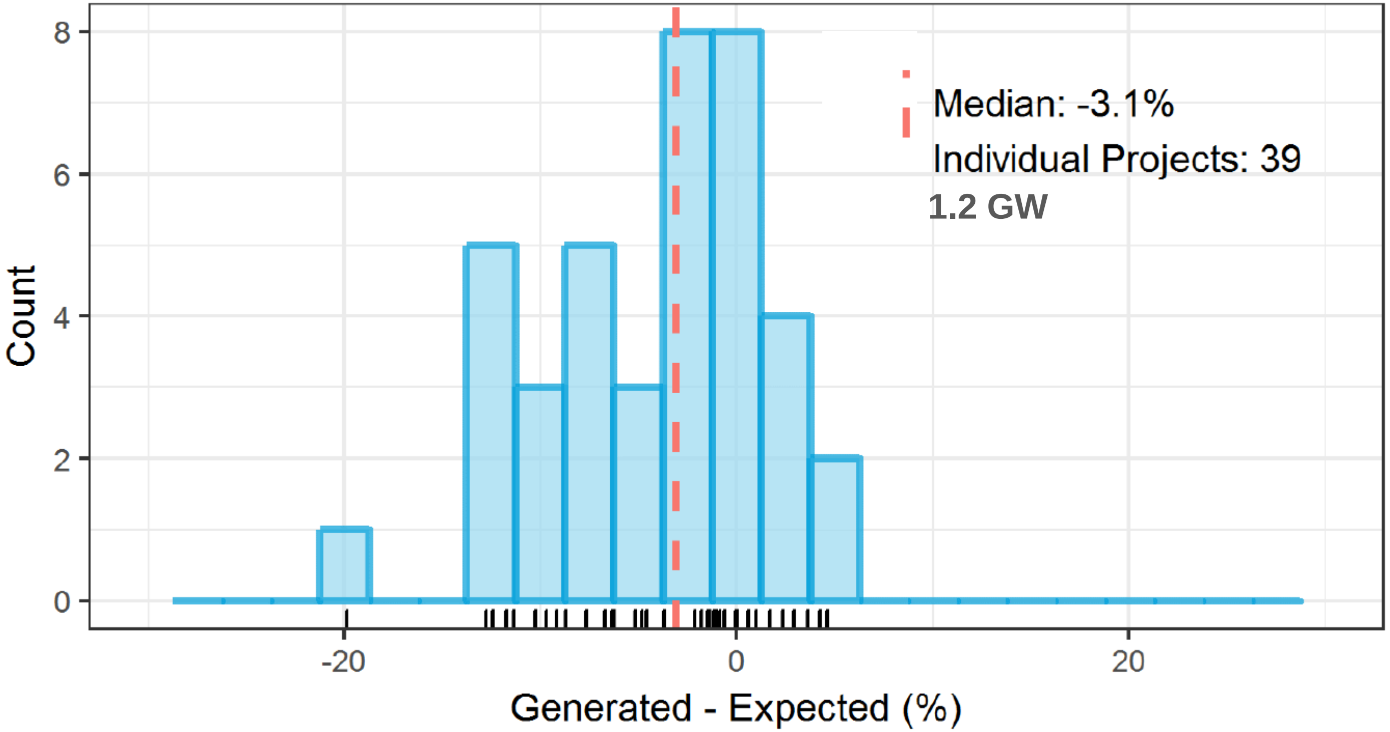




Sources: SRECTrade, https://www.srectrade.com/, accessed 10/25/18.

PV System Underperformance

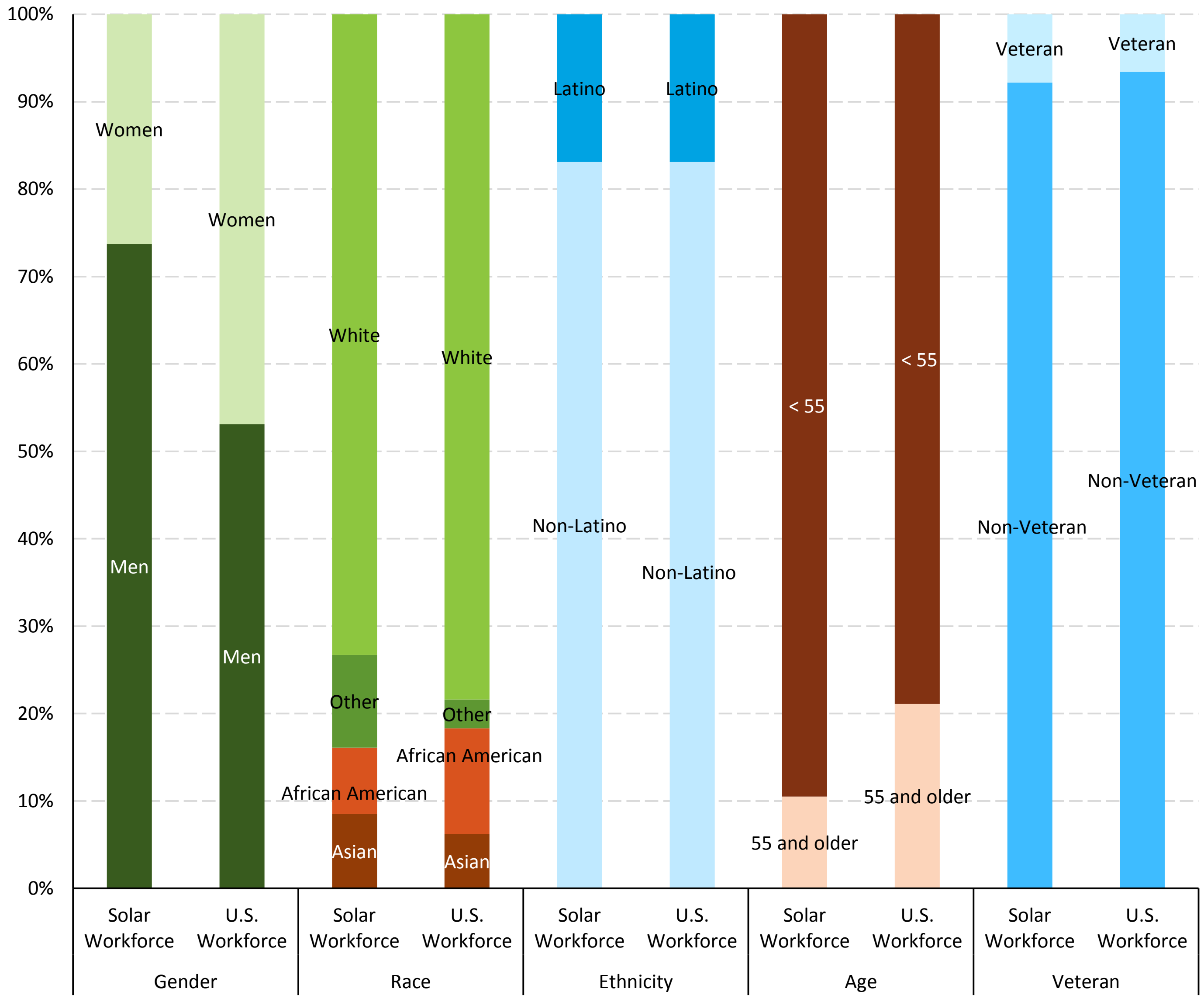
- A recent report, *Solar Risk Assessment: 2019*, published data and analysis from 10 leading solar firms on PV performance and the underlying drivers of deviation from electricity generation predictions.
- The report found that, over a data sample size of 1 GW of projects, predicted energy was approximately 3% greater than measured production, in the median case. However, that gap disappeared when omitting first-year production data, suggesting lower availability in the first year.



- After analyzing a separate data set, the authors of the report also found that of more than 200,000 PV projects, the probability of the P99 production occurring (i.e., the annual production value in which it is estimated will be exceeded 99% of the time) would actually occur 6.3% of the time, not 1%.
  – P99 values help determine PV loan sizing and therefore, defaults are actually more likely to occur.
- The report attributes several explanations to the lower than expected production:
  – Variation in module quality of Tier 1 module manufacturers and manufacturing lines
  – Significant underperformance from certain systems due to 30+ days of inverter downtime caused by slow turnaround from the inverter manufacturer when a problem occurs (and a lack of accountability in the original sales contract)
  – Significant reduction in O&M pricing, caused by competition—well below what is required to sufficiently service a system
  – Incomplete EPC punch list due to project scheduling and budget.

Source: "Solar Risk Assessment: 2019 Quantitative Insights from the Industry Experts."

Solar Workforce Diversity



- SEIA and the Solar Foundation published a study on diversity and inclusion in the solar workforce, as well as a compendium of best practices on improving workforce diversity.
- The solar industry tends to have fewer women, older staff, and African Americans than the U.S. workforce overall.
- At solar firms, men are more likely to be represented at the management level than women (37% to 28% respectively), and executive-level positions are predominantly comprised of white males (88% white, 80% men).
  - Consistent with this trend, women make 74% of the wages men earn in the solar industry.
- Three of the top five solar-firm recruitment methods relied on the use of professional or personal networks to find candidates, which can lead to a lack of diversity.
  - People of color were much less likely to find their current position by employee referral or word of mouth.
- Companies that are more diverse tend to be more profitable; additionally, the United States is growing more diverse over time so it will be critical for companies to tap into the full labor market.

Sources: SEIA and The Solar Foundation: "U.S. Solar Industry Diversity Study 2019;" "Diversity Best Practices Guide for the Solar Industry."

Tax Benefits of Investing in an Opportunity Zone

Example

- Five-year deferral and 10% step-up in basis reduces the capital gains tax, in real terms, by 29%.
- Seven-year deferral and 15% step-up in basis reduces the capital gains tax, in real terms, by 40%.
  - $0 tax basis could also mean a reduction in value of solar depreciation expense by 7%.
    - The percentages may not be of equivalent value based on the equity contribution versus the total cost of the project.

Year 0

- Sale of $1 million asset, invest within 180 days—no taxes owed
- Tax basis: $0

Held for 5 Years

Year 5

- 10% increase in basis ($100,000)
- Taxed on $900,000 (or FMV if lower) if sold

Year 7

- 5% increase in basis ($150,000)
- Taxed on $850,000 (or FMV if lower)
- Capital gains accrued on or before December 31, 2026 (sale or no sale)

Held for 7 Years

Year 10

- Taxpayer sells asset for $2 million.
- Basis in the investment is deemed to be FMV; no *federal* taxes owed

Held for 10 Years

‘19 ‘20 ‘21 ‘22 ‘23 ‘24 ‘25 ‘26 ‘27 ‘28 ‘29

Notes: Assumes a capital gains tax rate of 20%, a combined corporate tax rate of 27.3% (state and federal), a discount rate of 6%, assumes depreciation is taken when the step-up in basis occurs, and that the first year of depreciation and the ITC flow to the tax equity investor.

DISCOVERING NEW OPPORTUNITIES

Emerging Markets

Income Trends among U.S. Residential Rooftop Solar Adopters

Galen Barbose, Sydney Forrester, Naïm Darghouth, and Ben Hoen

February 2020

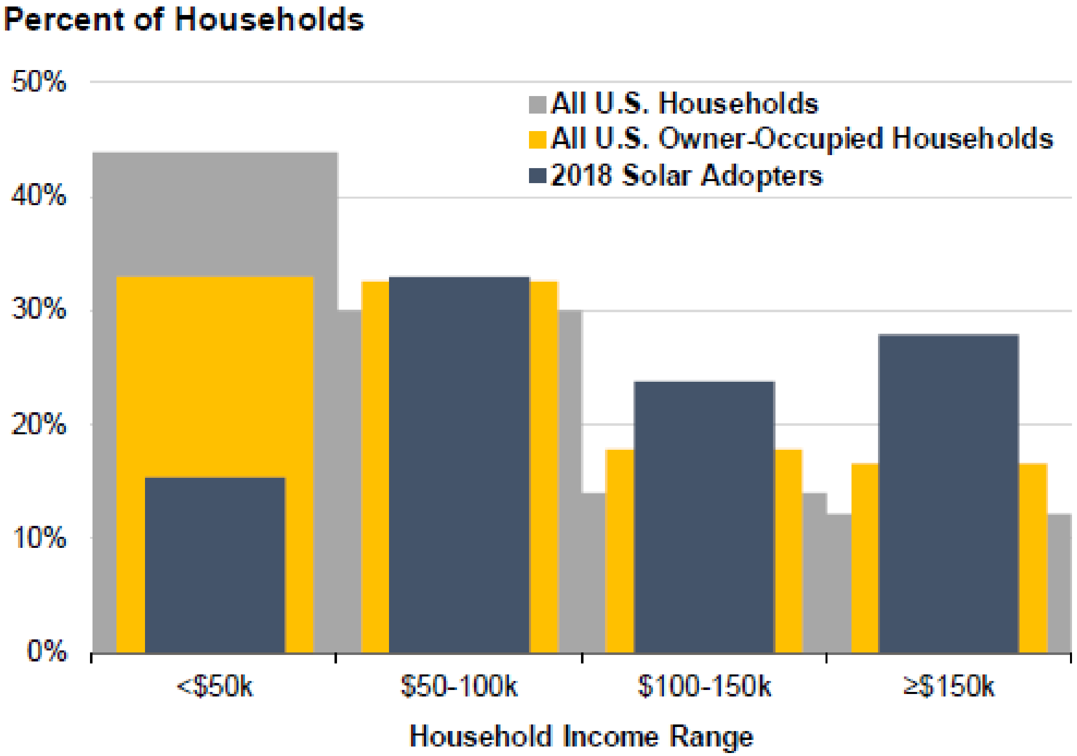
BERKELEY LAB

U.S. DEPARTMENT OF ENERGY

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34158 and Contract No. DE-AC02-05CH11231.

LAWRENCE BERKELEY NATIONAL LABORATORY | ENERGY TECHNOLOGIES AREA | ENERGY ANALYSIS AND ENVIRONMENTAL IMPACTS DIVISION

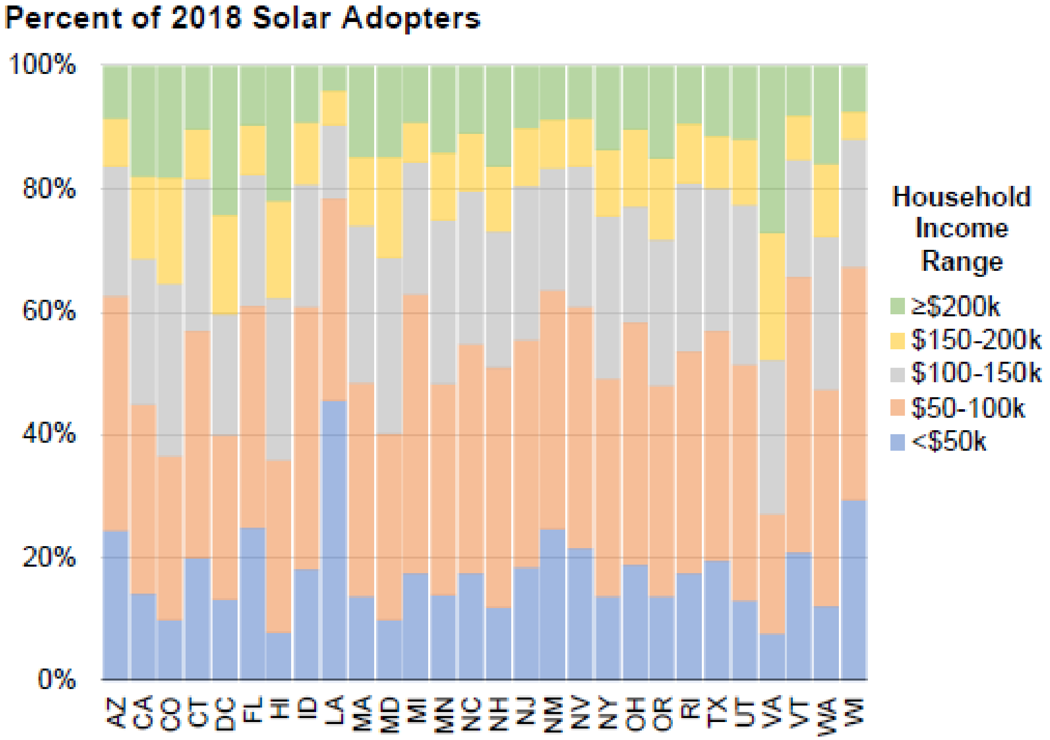
Income Distribution of Solar Adopters vs. U.S. Population



Notes: Based on all states in the data sample. Incomes are consolidated into this set of bins in order to conform to Census statistics, which are provided in $50k increments for incomes ≥$100k, and which group all incomes ≥$150k for owner-occupied households.

- Comparing to Census data requires that we consolidate the income bins, as shown here
- Solar-adopter incomes skew high relative to all U.S. households
  - Income disparities are most pronounced at the low and high ends
  - Whereas HHs with incomes in the $50-100k range are proportionately represented
- Skew is less pronounced if comparing to just owner-occupied households (OO-HHs)
  - Solar adoption occurs primarily among single-family owner-occupied homes (due to owner-control of rooftop, owner/tenant split incentive)
  - Illustrates how home-ownership can be a key driver for income disparities between solar adopters and the broader population

Solar-Adopter Income Distributions Across States

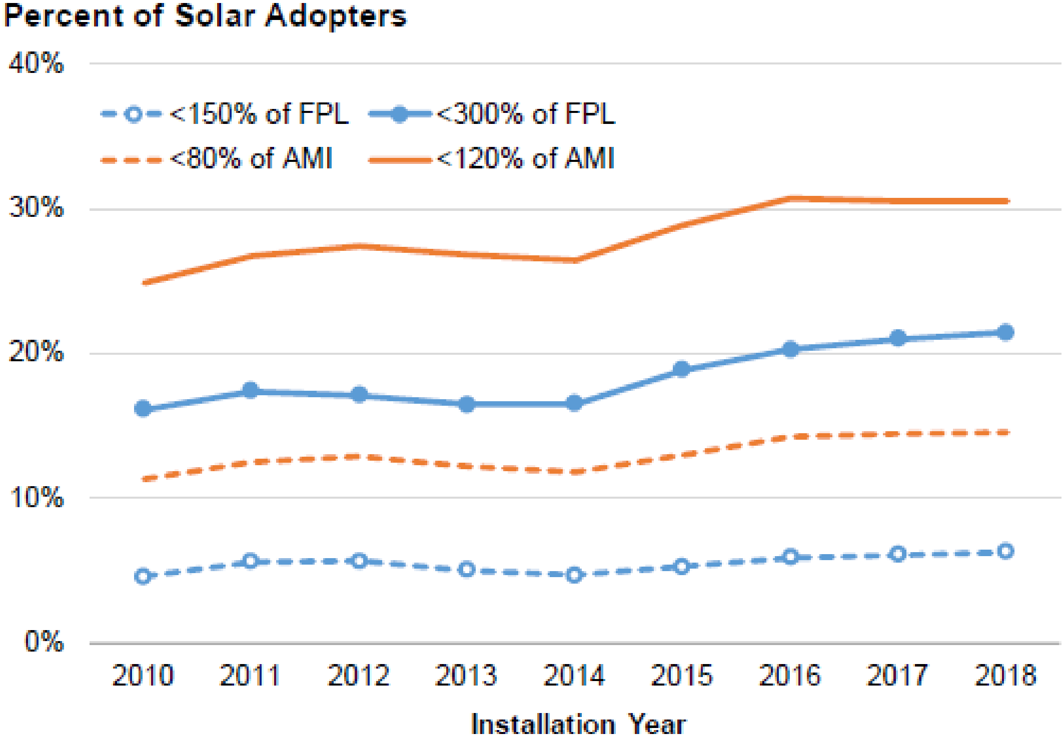


Notes: The figure excludes states for which the dataset contains fewer than 100 systems or less than 10% market coverage in 2018 (see appendix slide 35 for sample size and market coverage by state).

- Solar-adopter income distributions vary across states, but in general, roughly:
  - 30-40%* of 2018 solar adopters have HH incomes in the $50-100k range
  - 10-20% have incomes ≥$200k
  - 10-25% have incomes <$50k
- Some notable exceptions (e.g., LA, VA)
- Differences across states can reflect:
  - Relative levels of solar market maturity
  - Utility rates and solar incentives, including LMI-oriented programs
  - Overall income levels in the state (or portion of the state for which data are available)

* *The ranges cited on this slide all refer to the 10th to 90th percentile range among states for each respective metric*

LMI Sample Share over Time



Notes: Income estimates are for the year 2019, irrespective of when the PV installation occurred. See appendix slide 42 for results showing the full income distribution over time in terms of both state percentiles and AMI.

- LMI shares are rising slowly over time, consistent with earlier trends based on absolute income levels
- Growth has been somewhat greater for higher LMI thresholds (<120% AMI and <300% FPL)
  - Percent of solar adopters with incomes <300% of FPL rose from 16-21% over the 2010-2018 period, while the percent <150% of FPL rose from just 5-6%
- Since 2016, LMI shares based on AMI have remained relatively flat, while shares based on FPL have continued to rise
  - May reflect differentially higher growth in solar adoption in lower-income areas

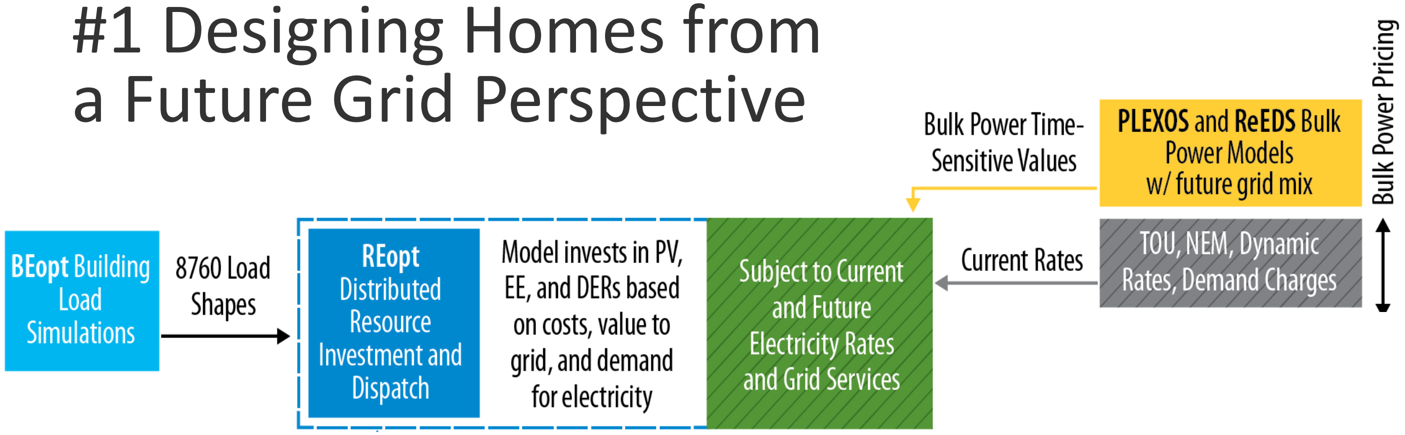
Scenario Planning and Technical Analysis

34160	NREL	Valuing Photovoltaics and Energy Efficiency in Buildings
29839	NREL	Distribution Grid Integration Costs (Subtask of Solar Technology Cost Modeling and Competitiveness Analysis)
34272	NREL	Techno-Economic Analysis of Solar Energy Technologies
34455	NREL	Valuation and Operational Performance of Solar plus Storage Power Plants
34271	NREL	Strategic and Programmatic Analysis to Support DOE
35659	NREL	High Penetration PV Scenarios

Scenario Planning and Technical Analysis:
Joint projects: H2@Scale, BTMS, SPIA (4-6 total)

Cambium Application to "Valuing PV + EE in the Built Environment" Project

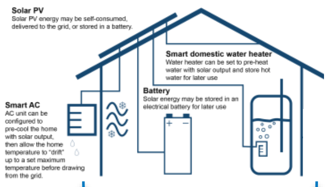
#1 Designing Homes from a Future Grid Perspective



Home design models BEopt and REopt don't have a good method of considering grid needs. Optimizing the design of a home against a quasi-retail rate based on future grid costs can be one way of considering future grid needs.

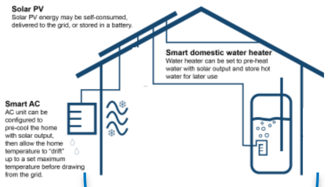
#2 Assessing the Grid Alignment of Homes

Home #1: PV/BESS/Flex Loads



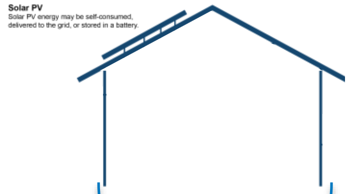
Home #1: Hourly net load
*
Cambium Prices
=
Grid Cost of Home #1

Home #2: PV/Flex Loads



Home #2: Hourly net load
*
Cambium Prices
=
Grid Cost of Home #2

Home #3: PV alone



Home #3: Hourly net load
*
Cambium Prices
=
Grid Cost of Home #3

Grid Cost of Home #1 < Grid Cost of Home #2 < Grid Cost of Home #3

Cambium Prices can be a way to compare how grid-aligned homes are from a future grid-cost perspective.

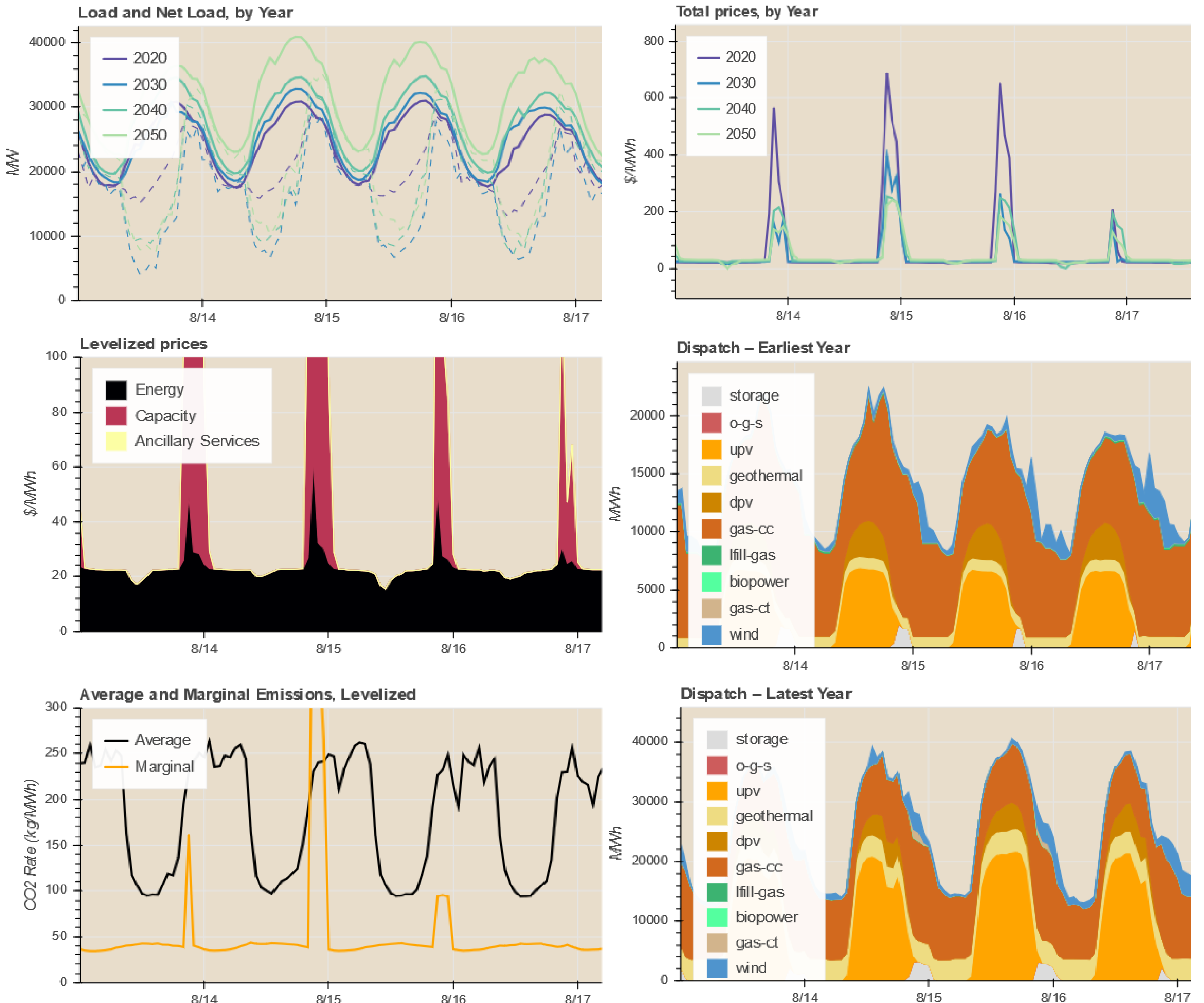
What is Cambium?

Hourly data for the future grid scenarios modeled in NREL's Standard Scenarios

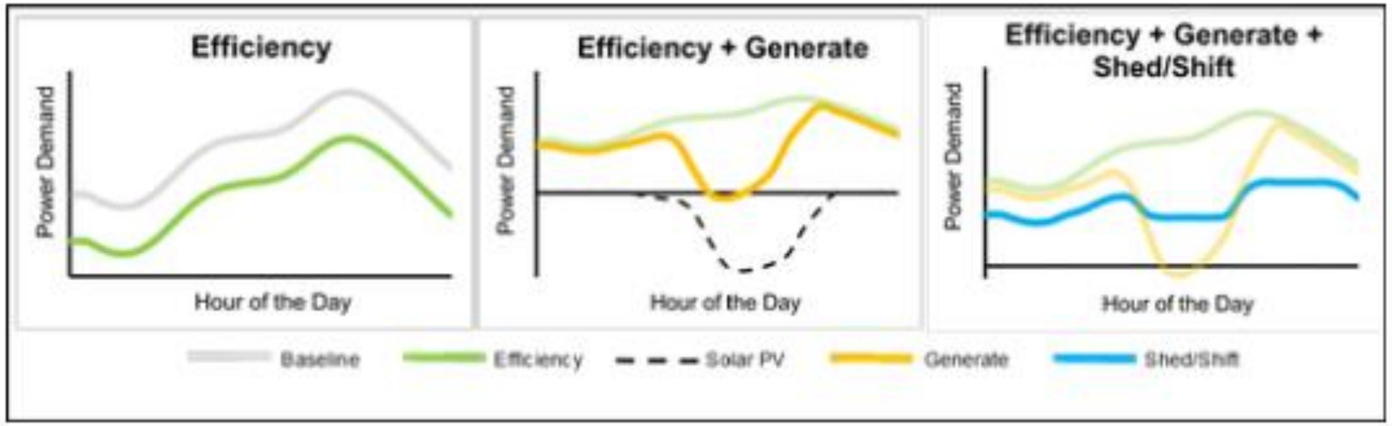
- Marginal costs (separated into energy, capacity, ancillary services, etc.)
- Emission rates (marginal and average)
- Load and net load
- Dispatch stacks

An interface for users to query the data

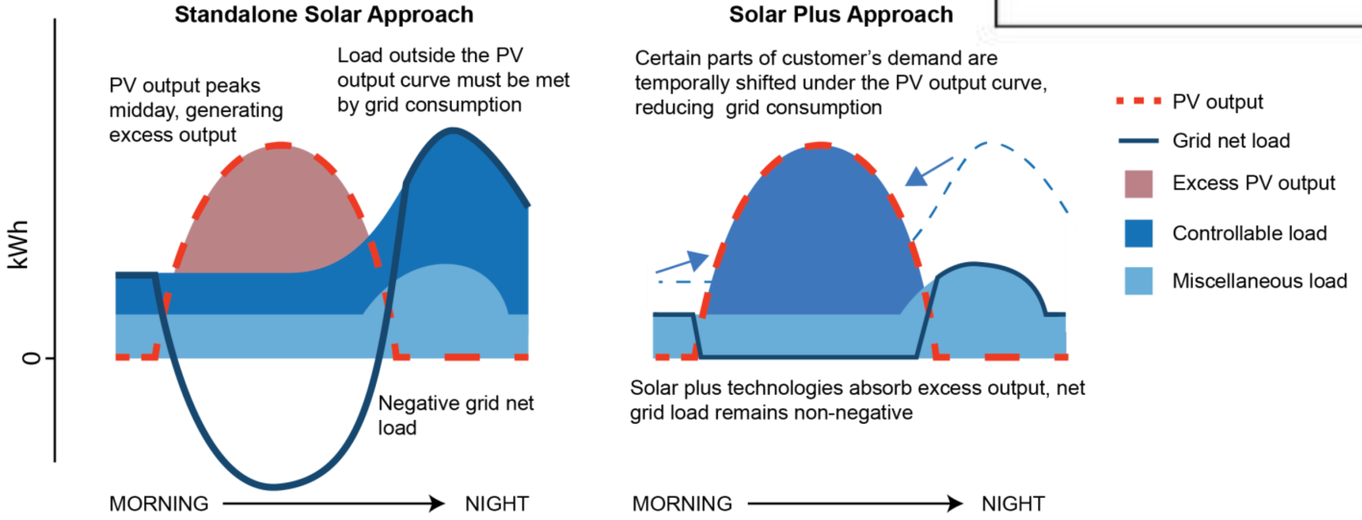
- Users specify region and timeframe (e.g. Colorado for 2020-2050), Cambium returns year-over-year, present-values, and annualized values.



… and we want to consider the potential for our EERE technologies to provide combined value.

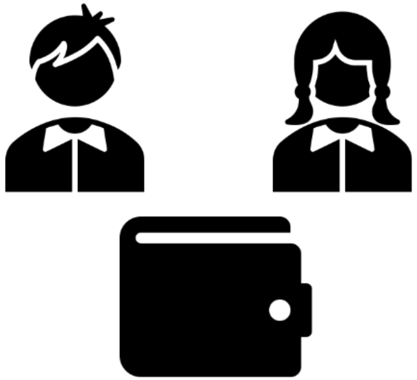


Source: Neukomm, M., V. Nubbe, and R. Fares. 2019. Grid-Interactive Efficient Buildings. Washington DC: DOE. www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

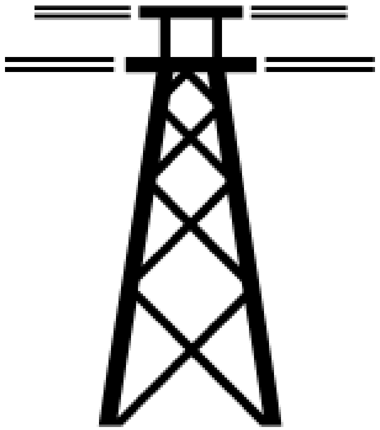


Source E. O'Shaughnessy et. al. 2017. *Solar Plus: A Holistic Approach to Distributed Solar PV*. NREL/TP-6A20-68371. https://www.nrel.gov/docs/fy17osti/68371.pdf

Metrics can capture the needs of multiple actors in the energy system…



Consumer needs



Grid needs

Societal needs

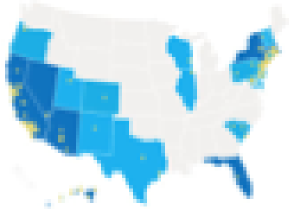
Benefits of Demand Flexibility

Benefit	Utility System	Building Owners/Occupants	Society
Reduced operation & maintenance costs	✓	-	-
Reduced generation capacity costs	✓	-	-
Reduced energy costs	✓	-	-
Reduced T&D costs	✓	-	-
Reduced T&D losses	✓	-	-
Reduced ancillary services costs	✓	-	-
Increased resilience	✓	✓	✓
Increased DER integration	✓	✓	-
Improved power quality	-	✓	-
Reduced customer utility bills	-	✓	-
Increased customer satisfaction	-	✓	-
Increased customer flexibility and choice	-	✓	-
Environmental benefits	-	-	✓

Source: Grid-Interactive Efficient Buildings (NASEO-NARUC GEB Working Group, April 10, 2019

Expanding the Toolbox with Stakeholder-identified Case Studies

Benefit
Reduced operation & maintenance costs
Reduced generation capacity costs
Reduced energy costs
Reduced T&D costs
Reduced T&D losses
Reduced ancillary services costs
Increased resilience
Increased DER integration
Improved power quality
Reduced customer utility bills
Increased customer satisfaction
Increased customer flexibility and choice
Environmental benefits



Solar as a Service

Hawaiian Electric

HI Self-Supply

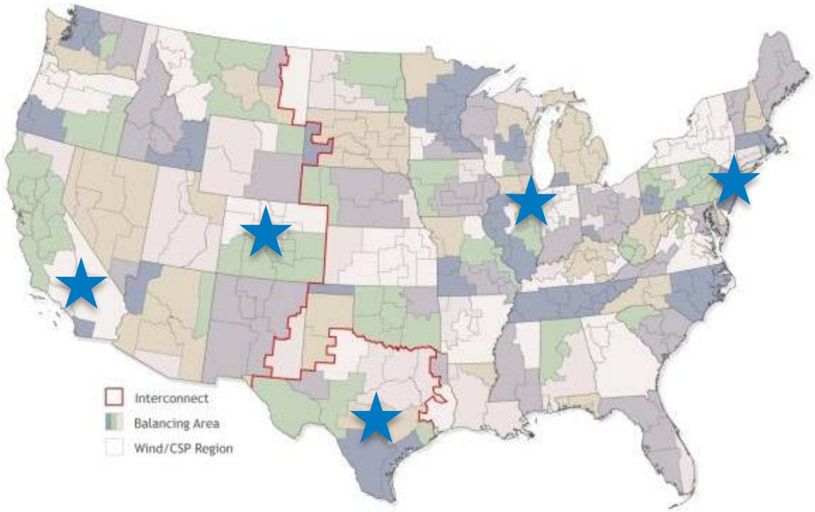
CA Time-of-Use

TX Virtual NEM

Bring Your Own Device 2018, 2019

Ex: Self-consumption:
- Phased out NEM
- Duck curve
- Local congestion

Ex: Export
- Bulk power fwd. capacity
- Mitigate local hosting impacts



Construct 4-5 case studies that expand our ability to value multiple building capabilities with new and existing metrics

Data and Models

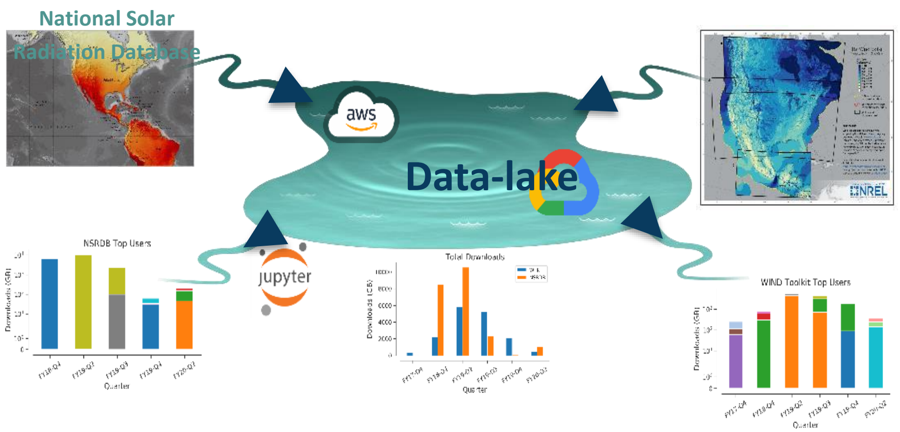
34163	NREL	DOE Open Energy Data Initiative
34168/34169	NREL/SNL	Transitioning Orange Button Orange Button for Operations & Modeling
34271	NREL	Strategic and Programmatic Analysis to Support DOE
34162	NREL	Open-Access ReEDS Model

SETO efforts for data openness

- Fund, build and support critical datasets for public benefits.
- SETO related key examples:
  - National Solar Radiation Data Base (Public)
  - Tracking the Sun (public)
  - Utility Rate Data Base (Public)
  - Durable Module Materials Consortium (DuraMat) Data Hub (Controlled access)
  - Photovoltaic Fleet Performance Data (Controlled access)
- Adopt & rollout a plan for implementing the FAIR data principles for open science and research data stewardship.
  - **F**indable – easy for non-experts to find the data
  - **A**ccessible – easy to access data directly or link it
  - **I**nteroperable – machine-readable, compatible with other datasets
  - **R**eusable - clear provenance and data usage license
- Examples of efforts towards FAIR:
  - Data.gov, DOE Data Explorer (Findable)
  - Open Energy Data Initiative (OEDI) (Findable / Accessible)
  - Orange Button Data standard (Interoperable / Reusable)

Open Energy Data Initiative (OEDI)

- Funded by SETO in collaboration with NREL, OEDI aims to improve and automate access of high-value energy data sets across the U.S. Department of Energy’s (DOE’s) programs, offices, and national laboratories.
- Cloud platforms such as Amazon Web Services (AWS) host high-value dataset online at no cost to tax payers
- DOE accelerate usability of open datasets through a new just-in-time data catalogue linked to cloud platform.
- Large datasets are publically available in standardized formats
- Anyone can perform sophisticated data operations on data using software tools and apps available on cloud platforms (e.g. Python)
- Allow people to collaborate and share data analysis scripts using open tools (e.g. Juypter notebooks)



Click . Compute . Uncover

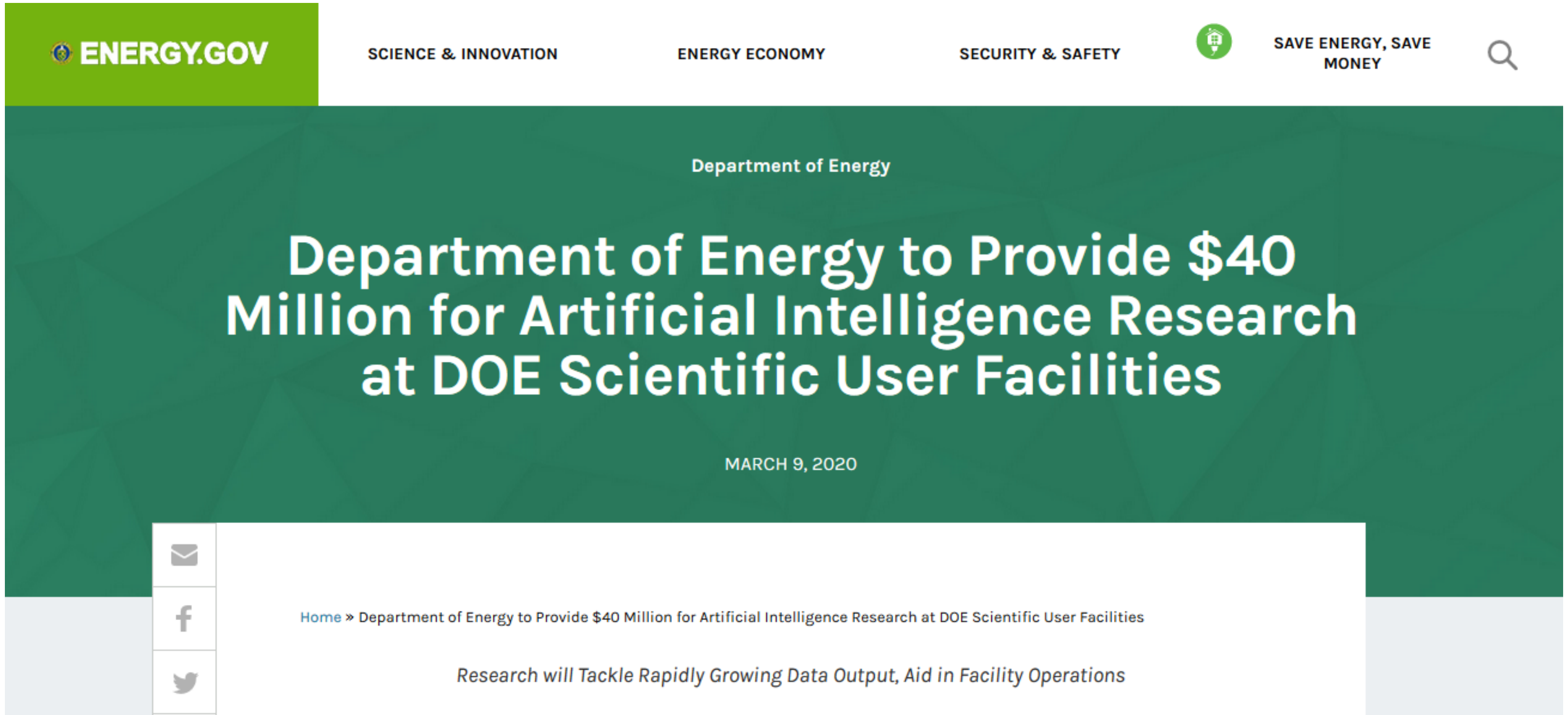
COLLABORATIONS AND SPECIAL PROJECTS

Cross-Office Collaborations and Special Projects

Fuel Cells	Hydrogen Systems: Demonstration of Integrated Hydrogen Production and Consumption for Improved Utility Operations
Buildings, Vehicles	Behind the Meter Storage (BTMS) Scenario Analysis
Strategic Priorities & Impact Analysis	Energy Storage and Flexibility Futures Study
Strategic Priorities & Impact Analysis	Grid Storage for Extreme Events
Office of Electricity	Puerto Rico Phase II Support
US Trade Representative, Dept of Commerce, Dept of State, Customs & Border Protection	Section 201 Trade Case

DOE and Administration Priorities

September 2019 – DOE Secretary Perry Announces new Artificial Intelligence office



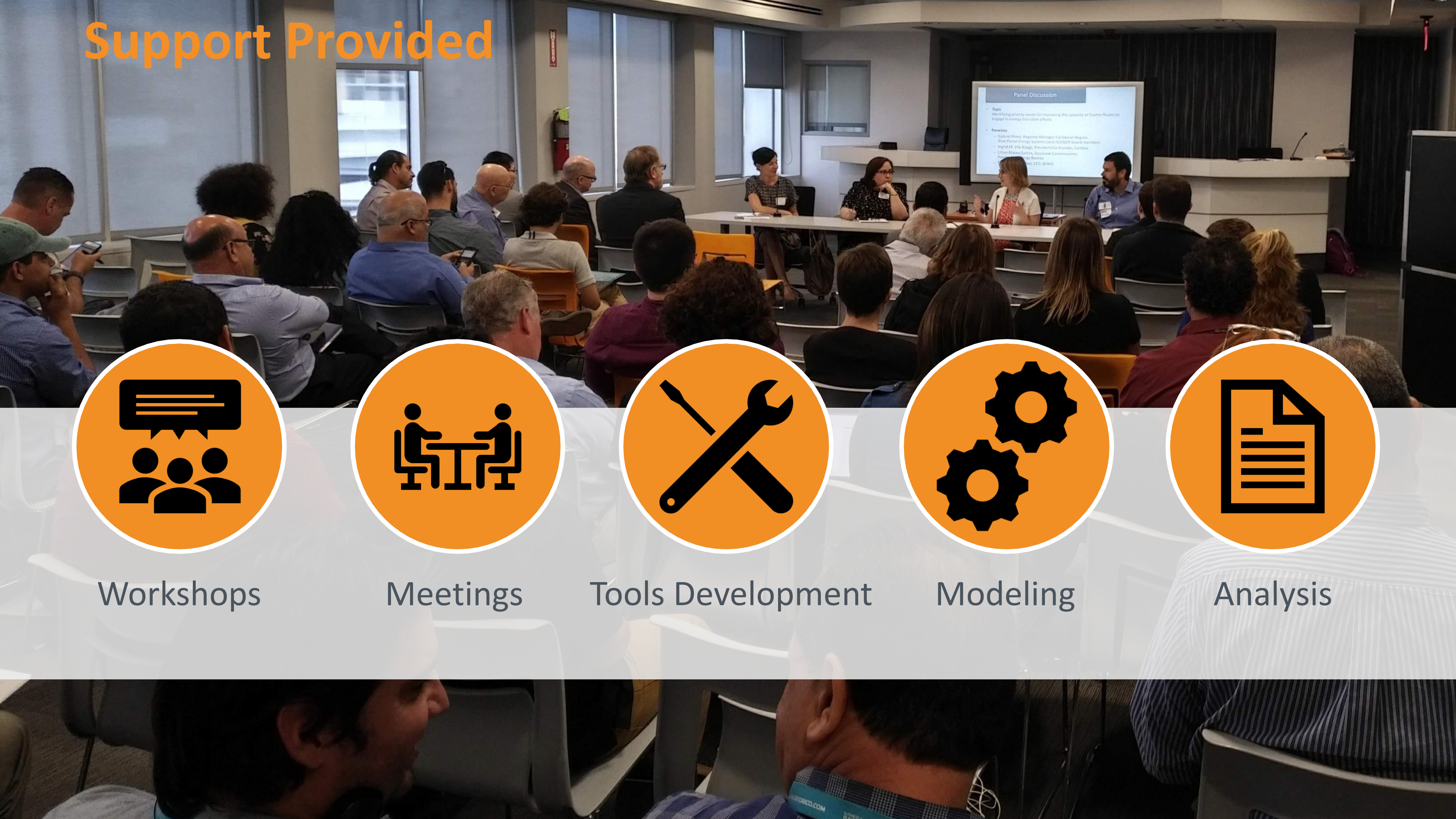
PUERTO RICO PHASE II SUPPORT

	DAMAGE OVERVIEW	REPAIRS	NEEDS
ENERGY	**100% of customers lost power,** causing other systems to fail (e.g., water, wastewater treatment plants) **Over 25% of transmission line** towers and poles were damaged **21% of the 1,110 gas stations** were closed	**73% of transmission lines** re-energized (as of 3/18/18) **87% of gas stations** reopened (as of 3/21/18)	**Power outages** remain intermittent **Significant work** remains on transmission and distribution systems
WATER	100% of PRASA customers **lacked drinking water** **Out of service:** **40 water treatment plants** of 114 **800 water pumping stations** **22 wastewater treatment plants** of 51 **222 sanitary pumping stations** of 714 **Untreated wastewater spills** in San Juan (13.7B gallons) and Manati, Mayaguez and Ponce (0.78M-1.19M gallons) **Damage to storage tanks** at 65 non-PRASA sites	As of 2/28/18: **100% of water and wastewater treatment plants** in PRASA's principal service regions operational **Drinking water restored** in 46 non-PRASA communities with solar-powered water pumps Multi-agency efforts underway to **stabilize Guajataca Dam**	**$2.51B** in initial estimates of hurricane damages and $16.45B in legacy pipe replacement **$215.8 M** of stormwater system damages in 51 of Puerto Rico's municipalities 
COMMUNICATIONS and IT	**95% of cellular sites** were out of service **91% of private telecom infrastructure** was damaged **80% of above ground fiber** and **85-90% of "last-mile fiber"** was destroyed **1 submarine cable** supported off-island communications for about 40 days after the primary cable landing station for many major telecom carriers flooded	**60% of communications infrastructure** was fully reliant on generators (as of January 2018) 	**4.3% of cell sites** out of service overall, but up to 25% of sites in some municipalities (as of 03/21/18) Information is limited about the extent of repairs and continued reliance on generators **Off-island communications** are restored for Puerto Rico but remain vulnerable in a future storm. Culebra and Vieques are relying on microwave systems until their submarine networks are operational. **$1.5B** in total damage to **private telecom infrastructure**

Hurricanes Maria and Irma Impacts

- 1.5 Million customers without power
- Full restoration took 11 (328 days) months and ~1500 residents not reconnected and no longer have utility service.
- 3.4 billion customer hours of blackout making it the largest blackout in history.
- Permanent closure of some generating assets. Further damage done to Costa Sur plant due to Earthquake in early 2020.
- >500,000 Homeowners 197,000 renters registered hurricane damage with FEMA. 90% of 1.23M households applied for assistance
- 70,000 evacuated due to crack in Guajataca Dam
- Loss of life estimates exceeding 4,000 (Harvard)

Support Provided



Workshops

Meetings

Tools Development

Modeling

Analysis

Phase II Modeling and Analytical support – 5 National Labs

Fuels/Interdependencies
- LNG Infrastructure
- Telecom Infrastructure
- Solar Resource and Supply Curves

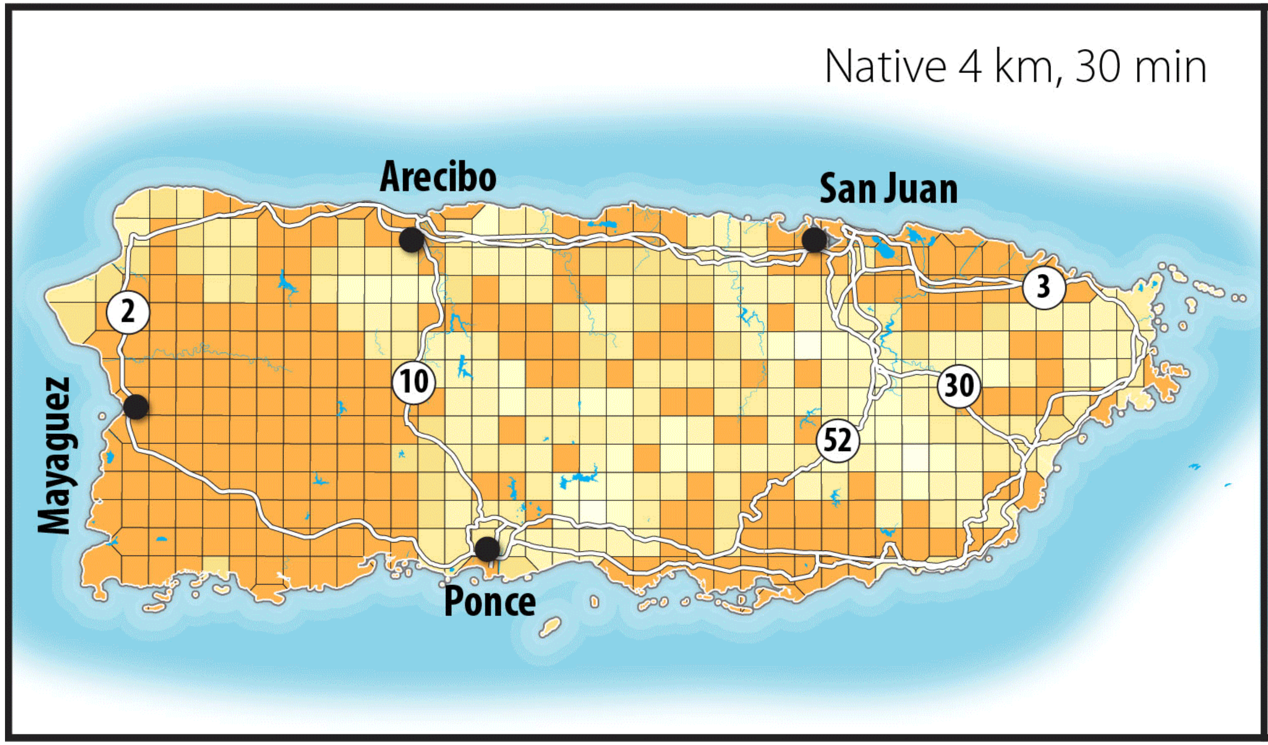
Bulk Power System
- Investment Support Tools
- Capacity Expansion Modeling (AURORA)
- Production Cost Modeling (FESTIV)
- System Stability Modeling (Epfast)
- Dynamic Modeling (MAFRIT)

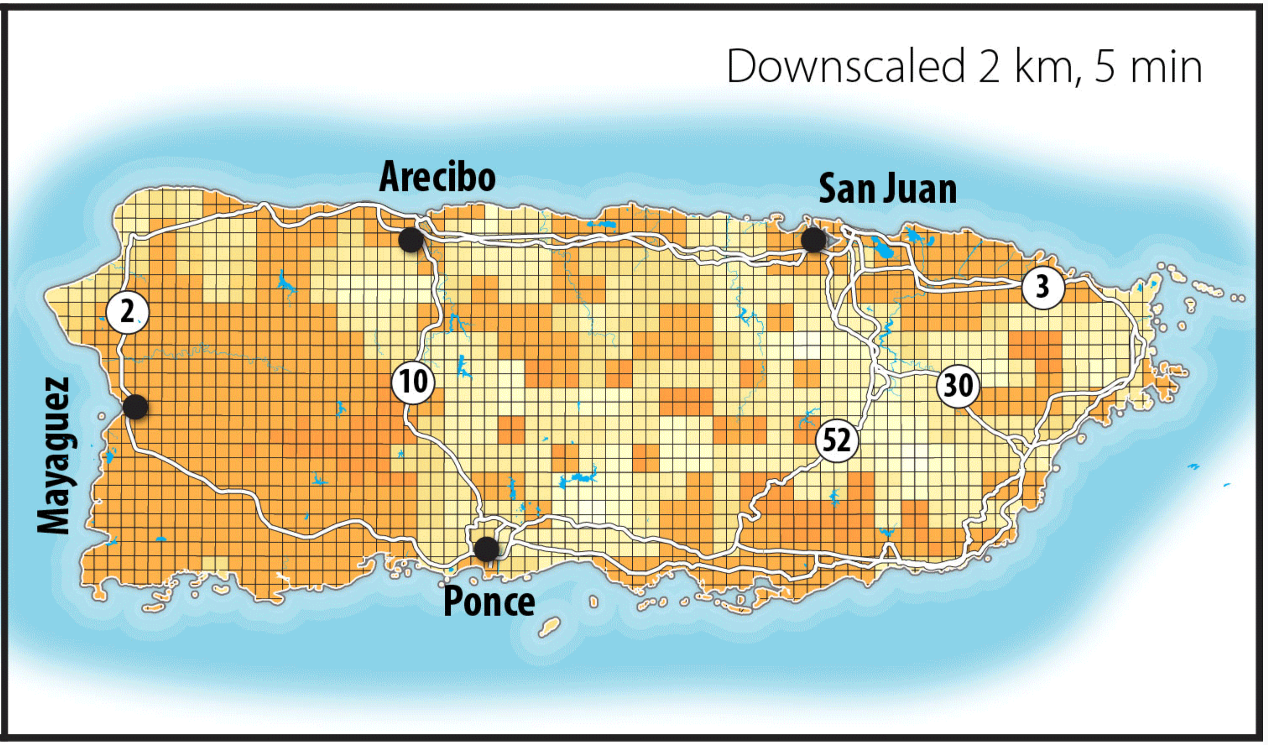
Transmission
- Protection and R/T Info
- Risk-Based Contingency Analysis
- Grid Asset Benefit-Cost Evaluations

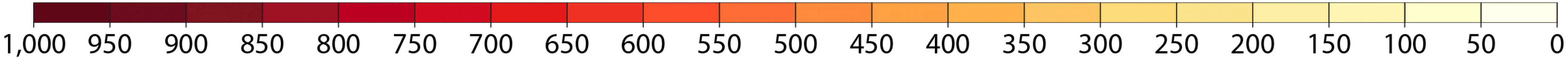
Distribution & Edge
- System Advisory Model & PVWatts
- DER Interconnection Standards
- DER Feeder Hosting Methodology
- Contingencies, Operations, and Storage Sizing for Islandable Sections
- GIS Resiliency Improvement Tool

Lead Lab Key:
- Argonne Natl Lab
- Natl Renewable Energy Lab
- Oak Ridge Natl Lab
- Pacific Northwest Natl Lab
- Sandia Natl Lab

Puerto Rico NSRDB Data Downscaling

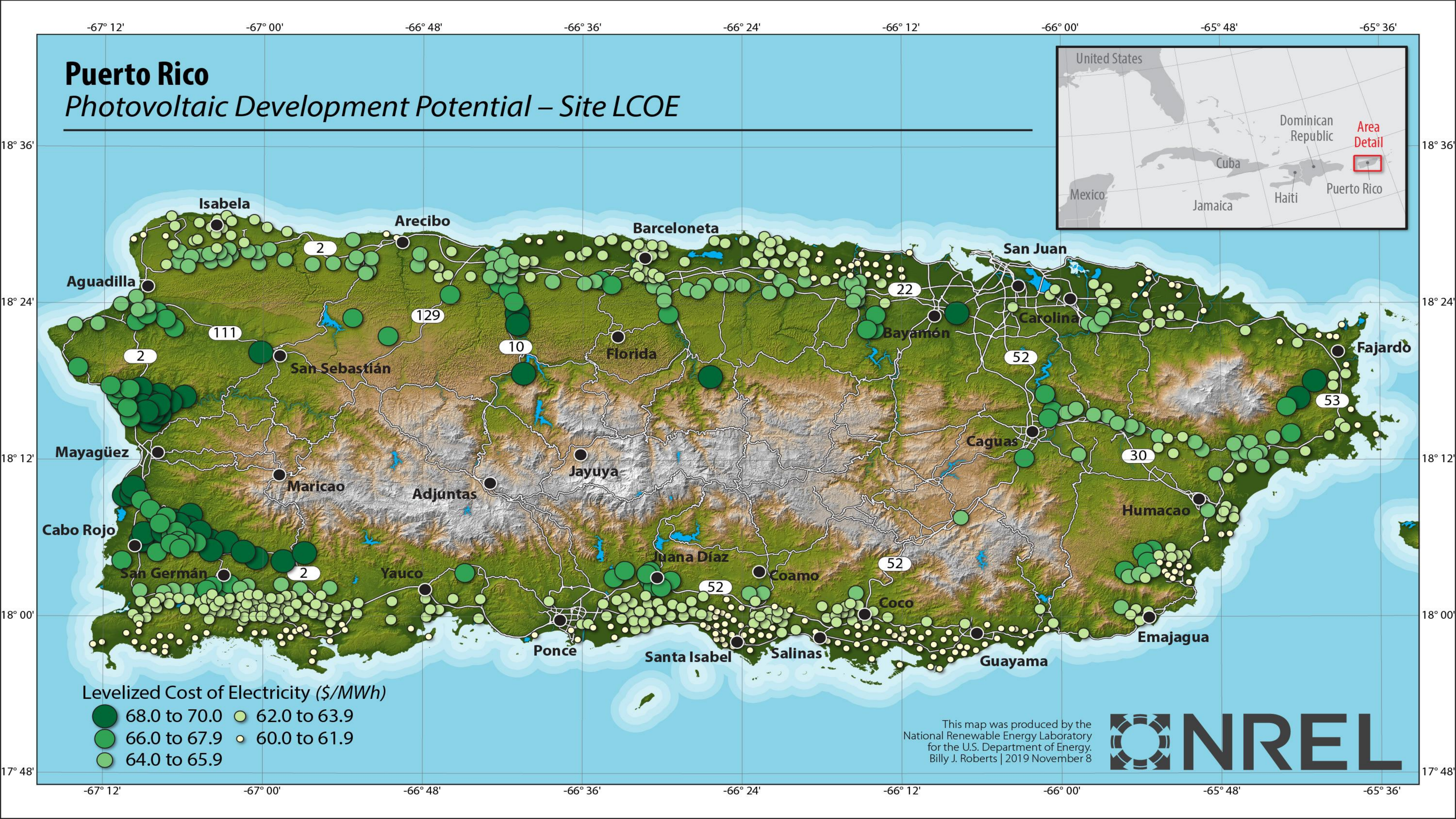




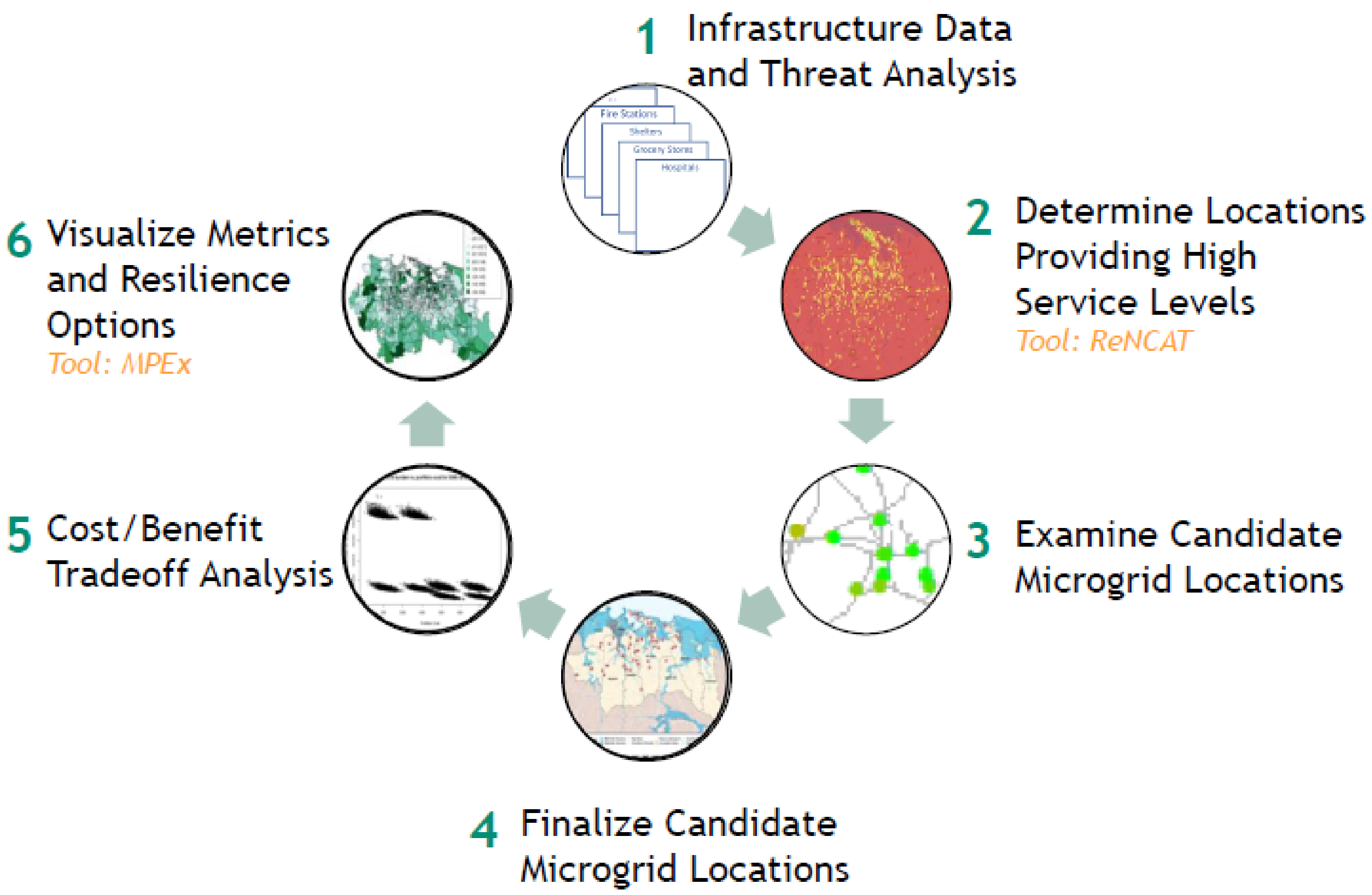


Timestamp: 1-1-2017 13:00 (UTC)

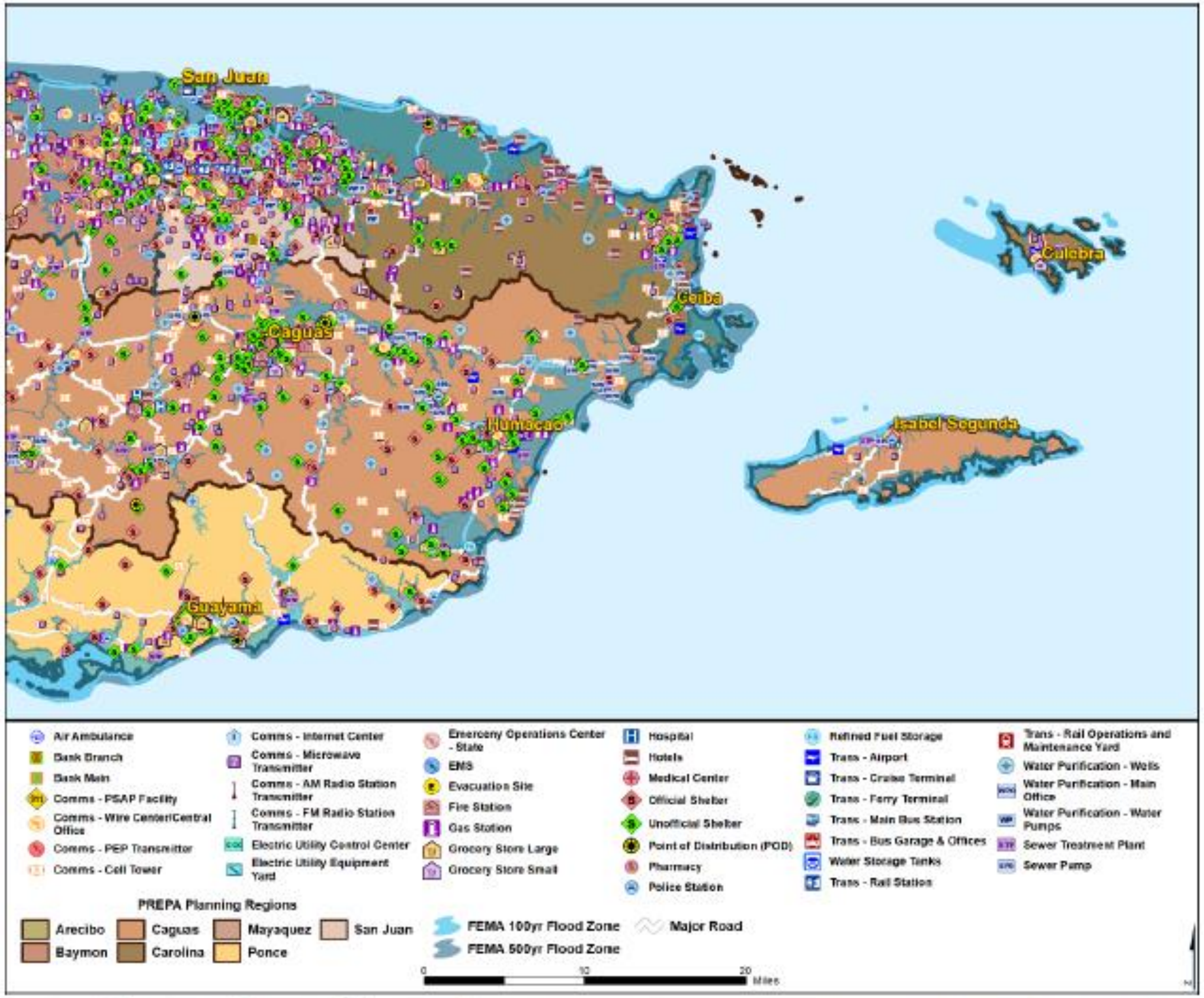
Produced by The National Renewable Energy Laboratory, April 17, 2019


Puerto Rico
Photovoltaic Development Potential – Site LCOE
Levelized Cost of Electricity ($/MWh)
68.0 to 70.0
66.0 to 67.9
64.0 to 65.9
62.0 to 63.9
60.0 to 61.9
Isabela
Arecibo
Barceloneta
San Juan
Aguadilla
Carolina
Bayamón
Fajardo
Florida
San Sebastián
Mayagüez
Maricao
Adjuntas
Jayuya
Caguas
Humacao
Cabo Rojo
San Germán
Yauco
Juana Díaz
Coamo
Coco
Ponce
Santa Isabel
Salinas
Guayama
Emajagua
United States
Mexico
Cuba
Jamaica
Haiti
Dominican Republic
Puerto Rico
Area Detail
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts | 2019 November 8
NREL

Sandia: Siting of Microgrids to Improve Community Resilience

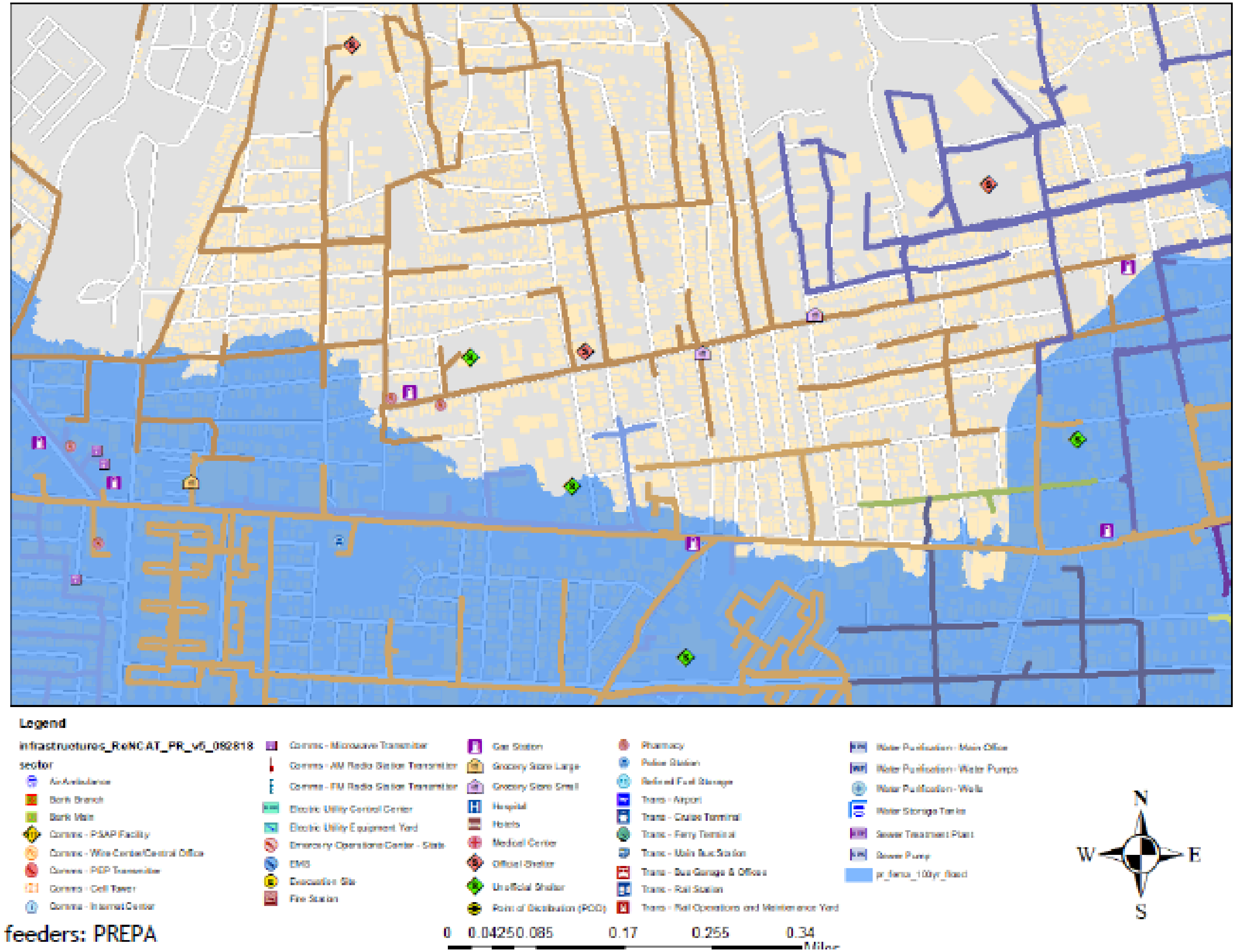


Critical Infrastructure



ReNCAT to Microgrids: Ponce Example

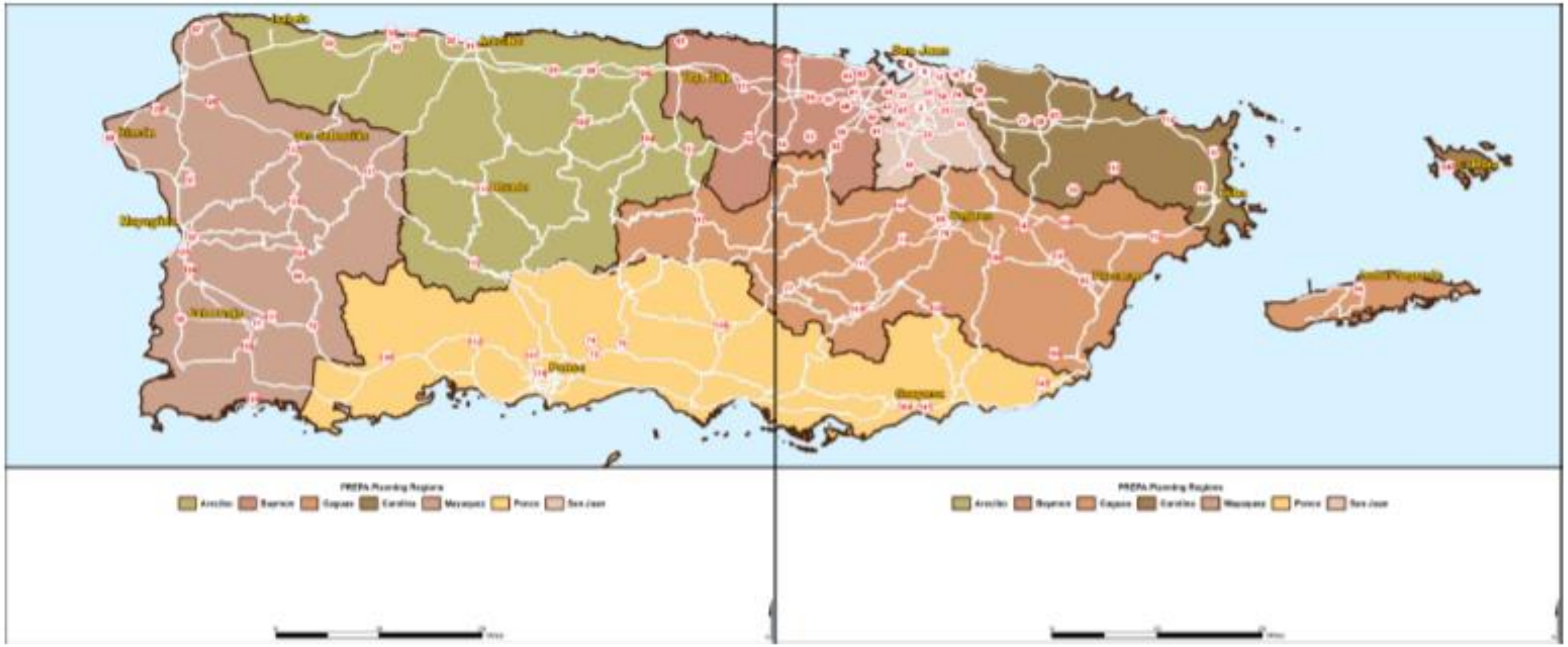
Find clusters of assets – ideally all on the same feeder - and minimize non-critical load



Distribution feeders: PREPA

Suggested Microgrid Locations

159 locations in total



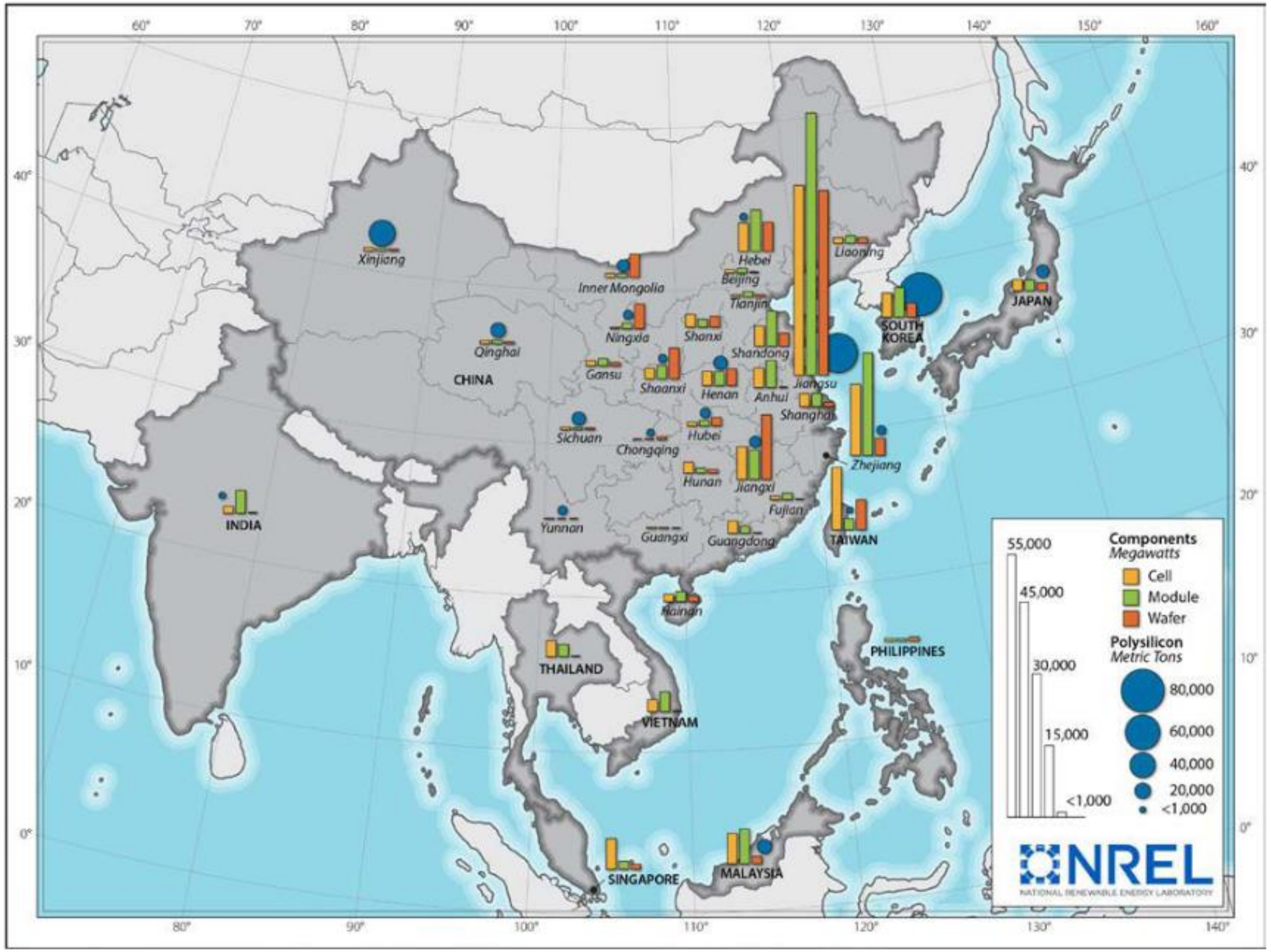
17 microgrids dominated by communications assets (cell towers, microwave transmitters, AM/FM Radio Transmitters):

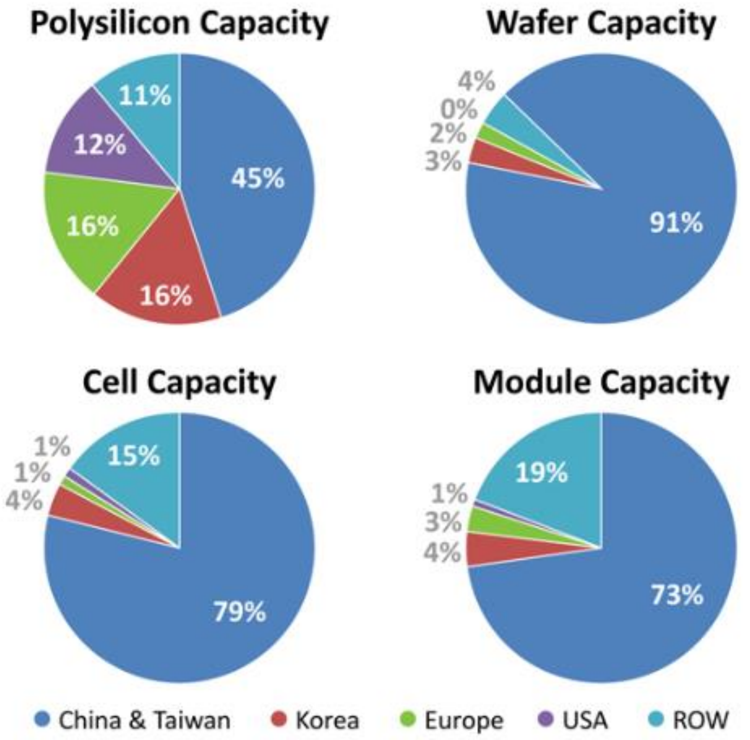
115, 113, 105, 99, 93, 89, 88, 87, 86, 85, 53, 51, 44, 41, 40, 30, 29

SECTION 201 SOLAR TRADE CASE

The Global Nature of the Photovoltaic Industry

Facility Locations and Manufacturing Capacities for the Top 500 Companies

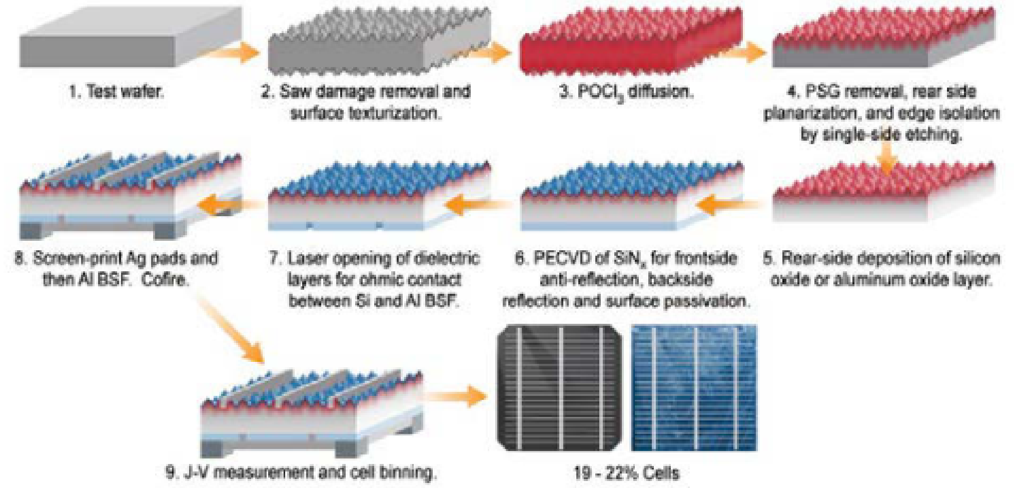


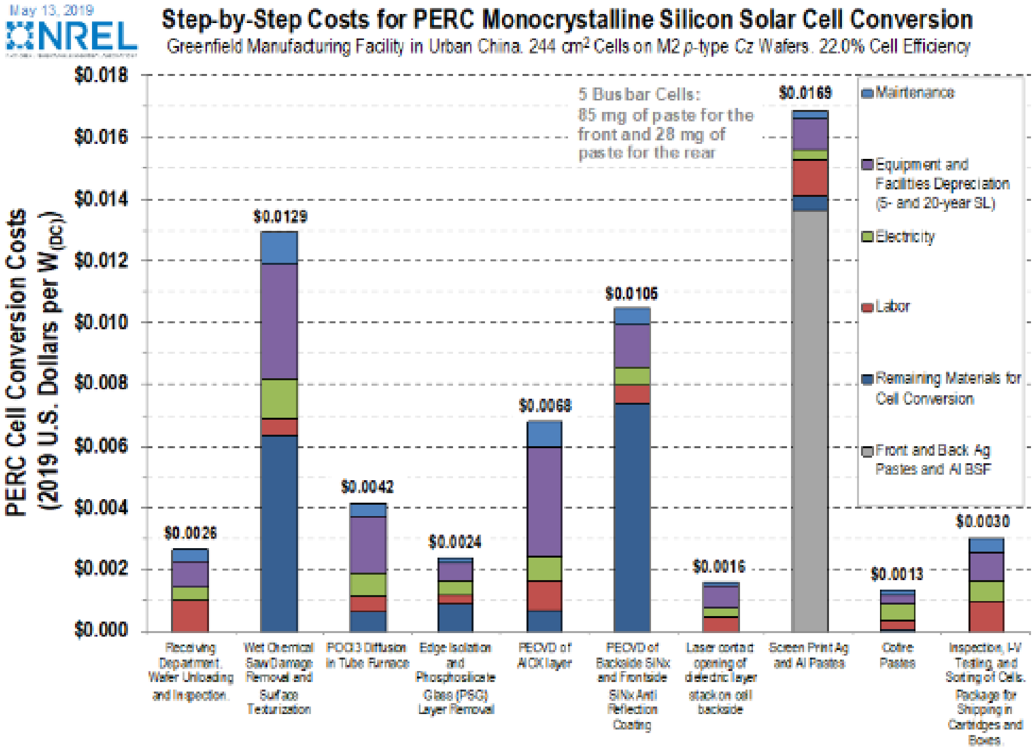


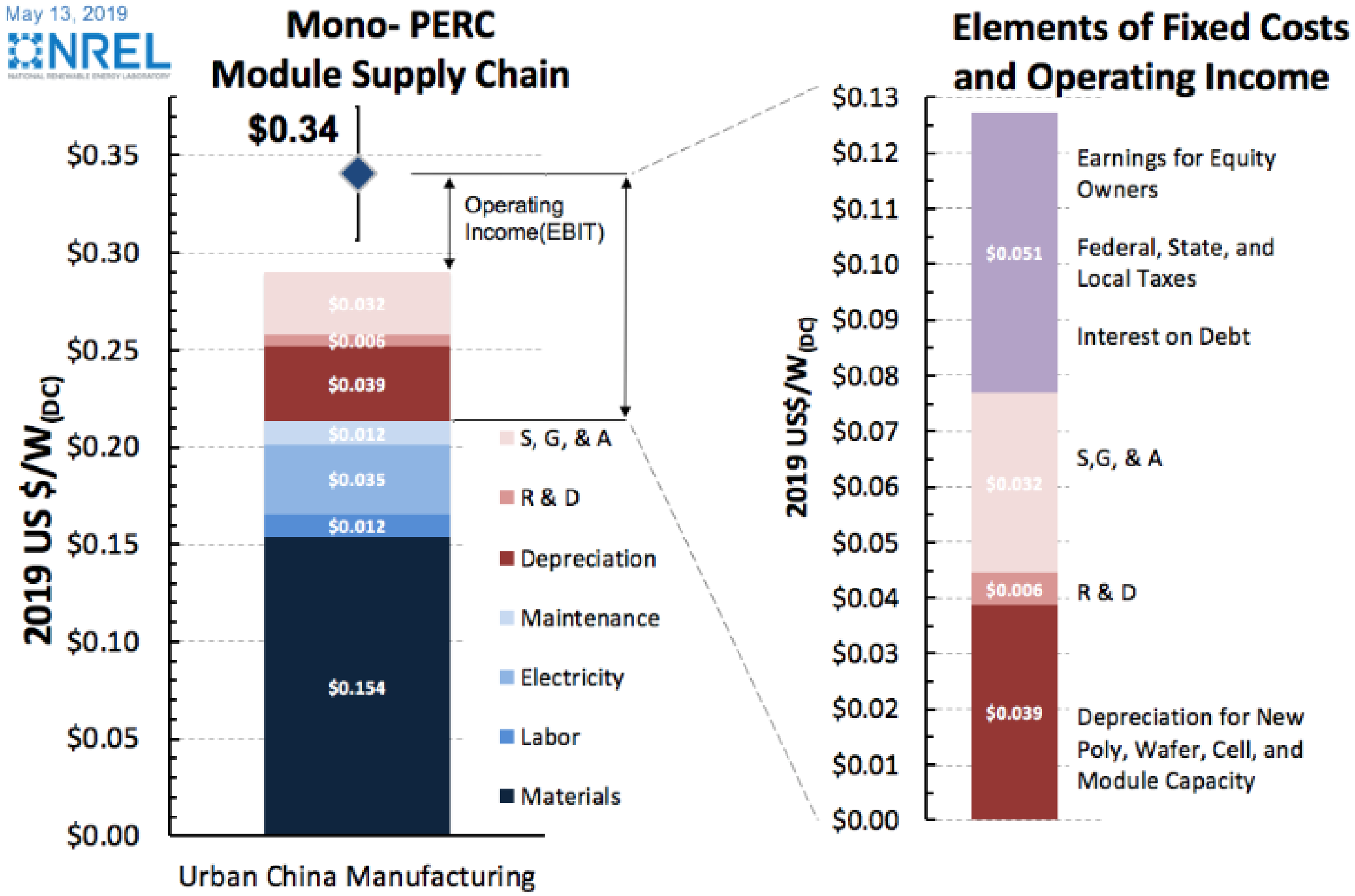
NREL | 4

Input data sources for map and pie chart: IHS and BNEF.

Example Cost Model Results for PERC Cell Conversion (Left) and a Complete Module Supply Chain (Right)

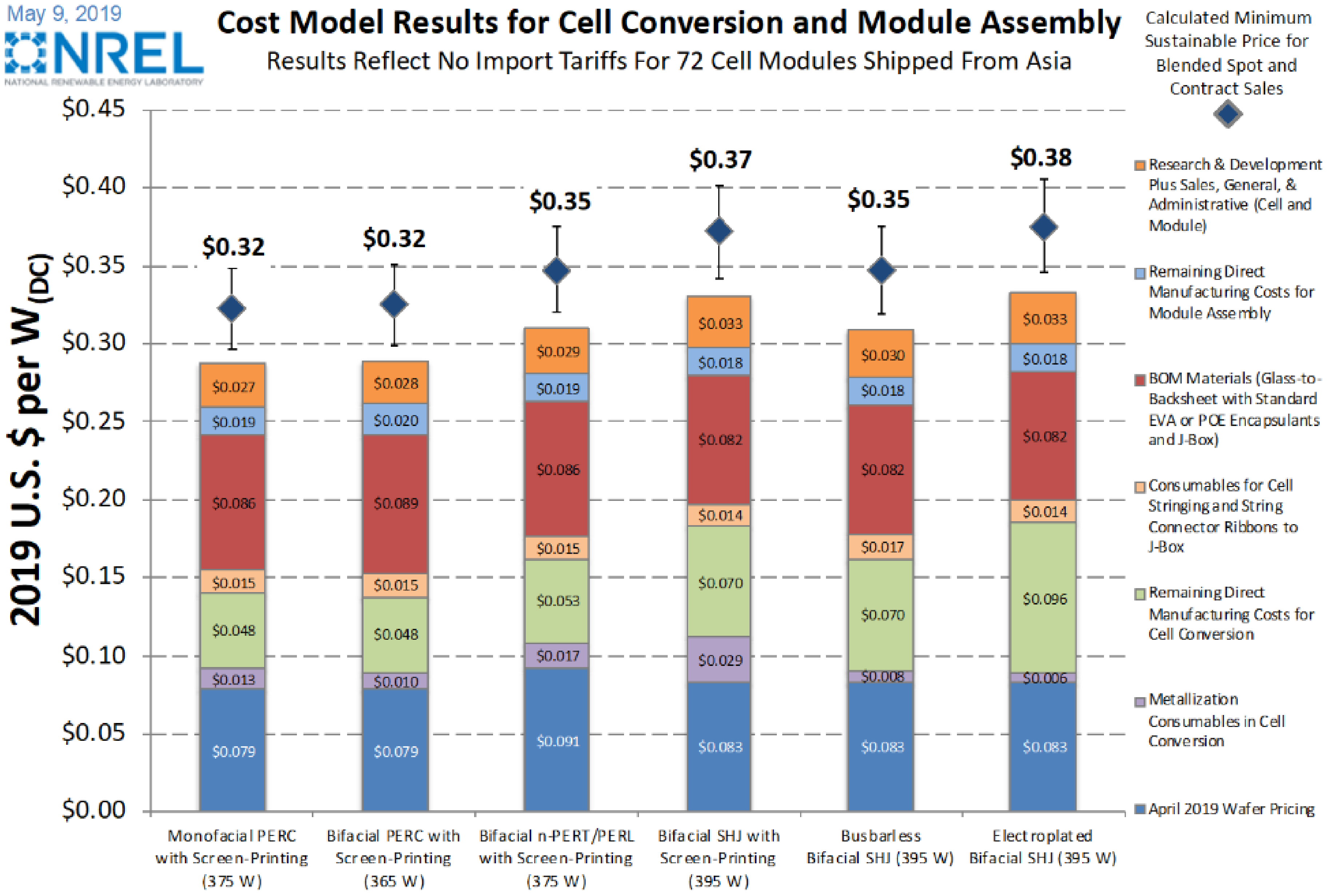






- 2018 industry medians: 2% of revenues reported for R&D and 11% of revenues reported for S, G, & A
- Minimum sustainable price based upon 15% operating (EBIT) margin. 5—20% operating margin used for error bars.
- Additional details given in "Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: 1H2018 Benchmark and Cost Reduction Roadmap" by M Woodhouse, et al., *Available online*.

Example Cost Model Results for Different PV Technologies



- Higher efficiency benefits $/W balance of module (BOM) costs and CapEx
- 10% price premium given for the *n*-type cell architectures PERT, HIT, and IBC
- Industry median 13% of revenues budgeted for R&D plus S, G, & A
- Minimum sustainable price based upon 15% operating (EBIT) margin
- Additional details given in "Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: 1H2018 Benchmark and Cost Reduction Roadmap" by M Woodhouse, et al., *Available online*.

Constant Change, New Opportunities?

- COVID-19

PVTECH

GCL-SI building 60GW integrated solar module megacomplex in Hefei City

By Mark Osborne | Mar 27, 2020 3:02 PM GMT | 0 Share

THE HILL

Lawmakers already planning more coronavirus stimulus after $2T package

- Stewardship of funds, talented and dedicated staff, ethics and culture
- Long-term guiding principles
- Maintain awareness of dynamic technology and market conditions
- Agility on annual basis

Systems Integration: Draft 2025 Goals

Reliable operation of a grid is demonstrated at scale during times when >50% of power is solar

A grid has demonstrated ramping up by 80% of peak net load in 2 hours beginning when >50% of power is solar

Zero interruption of solar electric supply is demonstrated under conditions of cyberattack and physical hazard

- Creating the infrastructure for acquisition, transfer, curation, and management of data, including measurements and forecasts, that provide observability of solar generation on the grid
- Building analytical tools and using them to provide insight into integrating solar generation with the grid
- Developing control, optimization, decision-support, and cyberdefense methods
- Studying and improving the hardware at the interface between solar energy and the grid, including power electronics, inverters, transformers, energy storage systems, and sensors
- Demonstrating the integration of solar technology with storage, flexible loads, and the grid

Concentrating Solar-Thermal Power: Draft 2025 Goals

A 700°C solar thermal receiver, storage, and delivery system has been demonstrated to be compatible with a >50% efficiency power cycle at a modeled cost of <$900/kW

An integrated heliostat field with >55% annual optical efficiency costs <$100/m^2

Levelized cost of solar process heat is <$0.02/kWh at a range of temperatures

2030 Goal: LCOE of $0.05/kWh for baseload CSP systems

- Improving the reliability and efficiency of power cycle and collector field components and systems
- Demonstrating low-cost, long-duration thermal storage as a dispatchable solar resource
- Developing technology for economical industrial process heat, including for applications such as solar fuels synthesis and desalination

Photovoltaics: Draft 2025 Goals

Primary Goal:

LCOE is <$0.03/kWh in utility-scale PV systems

90% of the mass of a PV module can be recovered in the US for a total cost of <$10

New capacity is combined with other uses, such as in agricultural PV or BIPV

- Extending service life, improving efficiency, and reducing risk
- Improving end-of-life materials characterization and separation
- Reducing cost through materials, manufacturing, and value-stacking in hybrid systems

Soft Costs: Draft 2025 Goals

LCOE <$0.10/kWh for residential PV systems

Increasing access to solar energy

Reducing the time to permit, install and interconnect PV systems

- Providing tools and training to make permitting and interconnection fast and easy
- Performing analysis to support the scalable and equitable integration of solar technology into the energy system
- Supporting new processes and mechanisms for efficient solar integration and deployment
- Providing objective information and analysis to inform decision-makers in business and government
- Offering workforce development for solar workers

Manufacturing: Draft 2025 Goals

New technologies enter U.S. manufacturing

U.S. solar manufacturing capacity increases across the value chain

- Supporting proof of concept, pilot production, technology transfer and scale-up of new products from US businesses
- Development of new technologies and business models